POWER PRESSES

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DEALING WITH THE LATEST TYPES OF MECHANICAL PRESSES AS USED IN ENGINEERING PRODUCTION, WITH A SURVEY OF HYDRAULIC PRESSES

INTENDED FOR INSTALLATION AND MAINTENANCE ENGINEERS, PRESS OPERATIVES, TOOL SETTERS, AND ALL EXECUTIVES WHO ARE CONCERNED WITH THE SELECTION, USE, AND MAINTENANCE OF POWER-OPERATED PRESSES

Prepared by a Staff of Technical Experts under the direction of

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PREFACE

POWER presses, from the small bench machines on the one hand to the large toggle or four-point suspension structures on the other, play a very important part in modern mass production. The small units turn out such articles as buttons in thousands an hour and the bigger machines deal with heavy-gauge metal and mould it to shape in a manner which is almost uncanny.

The aim of this book is to give, within a reasonable compass, an account of the important types, their construction, mode of action, and the work they perform. The experience of press designers and manufacturers of crank presses is that the fundamental points concerning them are not always clearly grasped, with the result that expensive machinery is either doing work which is small in comparison with its powers or else is being used for operations beyond its capacity.

The number of different types of crank presses made is very large, but an attempt has been made to clarify what is undoubtedly a confusing picture. After a review of the various makes and designs of presses detailed examination is made of special processes such as channelling, bending, etc., and the machines available for the work.

Consideration of the metal being worked is inseparable from the presses themselves. The subject itself is so extensive that it has only been possible to crystallise some of the essential practical points with which the press shop is concerned. But the opportunity has been taken of giving a short account of what occurs in a metal, under stress in the press, at the moment that plastic flow begins, and some of the most common defects encountered in producing finished work are dealt with.

The important subject of lubrication of the metal as it is being drawn through the die is also summarised. There is a separate chapter on safety guards for presses.

A list of important papers which throw light on the practical problems which are encountered in forming and deep drawing metal sheet is included. The list is not meant to be complete, and indeed it cannot be, for the literature of the subject is too large. But it has been thought wise to include it, since the reproach is often heard that if only the findings of the investigators filtered through to the press shop, there would be a great improvement in press performance.

The publishers wish to thank the many makers of crank and hydraulic presses who have helped, for their generous and expert assistance. Metal producers have been equally ready to place their knowledge at our disposal, and to the collaboration of both we are indebted for the many

excellent pictures which, it is hoped, will serve to give a balanced if necessarily condensed account of the subject. The excellent pictures in the chapter on the plastic flow of metals are reproduced by the kind permission of the Editor of the *Journal of the Institute of Metals*, to whom we are additionally indebted for allowing us to draw freely on the original text of Dr. Korber which accompanied them.

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POWER PRESSES

Chapter I

MODERN TYPES OF POWER PRESSES

ALL power presses have certain features in common, although dimensions of the whole or various parts will vary according to the nature of the duty they have to perform. The moving part is known as the ram, and is perhaps the most important. It is the ram which actually does the work, through the medium of the various dies. It is usually arranged to operate between guides formed in the frame of the press, these permitting vertical movement without side play.

The ram is connected to the crankshaft by a connecting rod, also called a " pitman," which may have either a ball or knuckle-joint connection to the ram. The length of the connecting rod may be varied according to the particular requirements of the work in hand, and is usually made in two parts and screwed together. It will be appreciated that this adjustment only changes the relative points at which the stroke operates and does not vary the range of the stroke, which is necessarily determined by the crankshaft throw.

Most presses have what is known as fixed stroke, but there are adjustable-stroke presses in which the stroke is varied by an eccentric bush at the crankshaft end of the connecting rod. Rotation of this eccentric gives an effect of variation of the crank throw, so that the stroke is varied in length. However, this advantage is somewhat offset by a certain loss of rigidity which often occurs. The crankshaft, which is carried in the main frame bearings, may be turned from either or both ends by a flywheel or a gearwheel.

A press may be either single geared or double geared, as it is called when there is an intermediate pair of gears between the flywheel and the crankshafts, or a press may be twin-geared, which means that the crankshaft is driven from both ends by gearwheels. The flywheel of the press is driven by a belt or by the gears, and stores up the energy which does the work.

As the flywheel is constantly rotating, while the ram, with the crankshaft, may only be required to turn intermittently, it is necessary to interpose some form of clutch, which the operator can engage at will, in order to set the crankshaft and ram in motion. Some clutches are of a safety pattern, which permits only one cycle of operations to take place, no matter how the operator manipulates the clutch reverse.

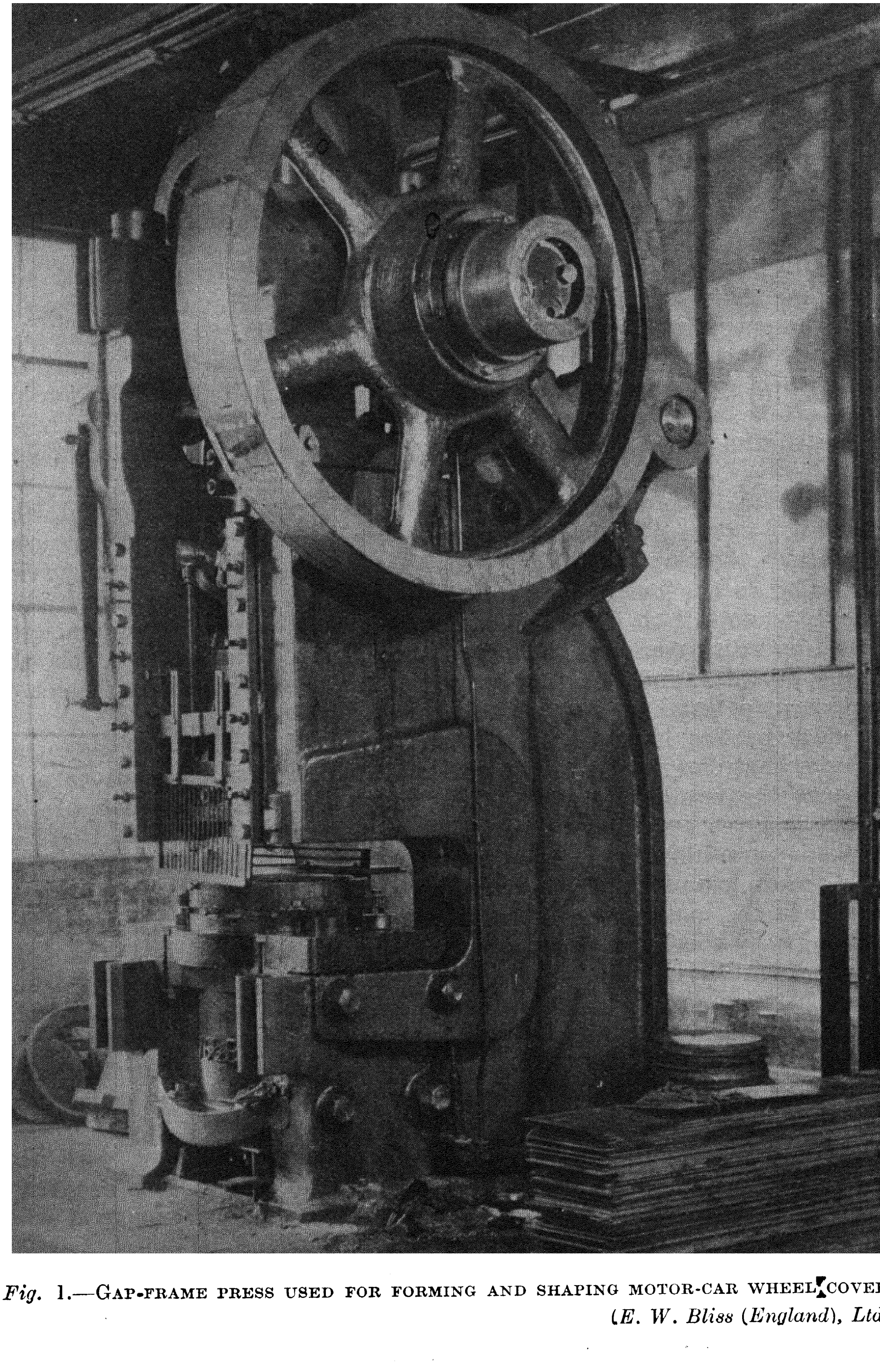


Fig. 1.—Gap-frame press used for forming and shaping motor-car wheel covers (*E. W. Bliss (England), Ltd.*)

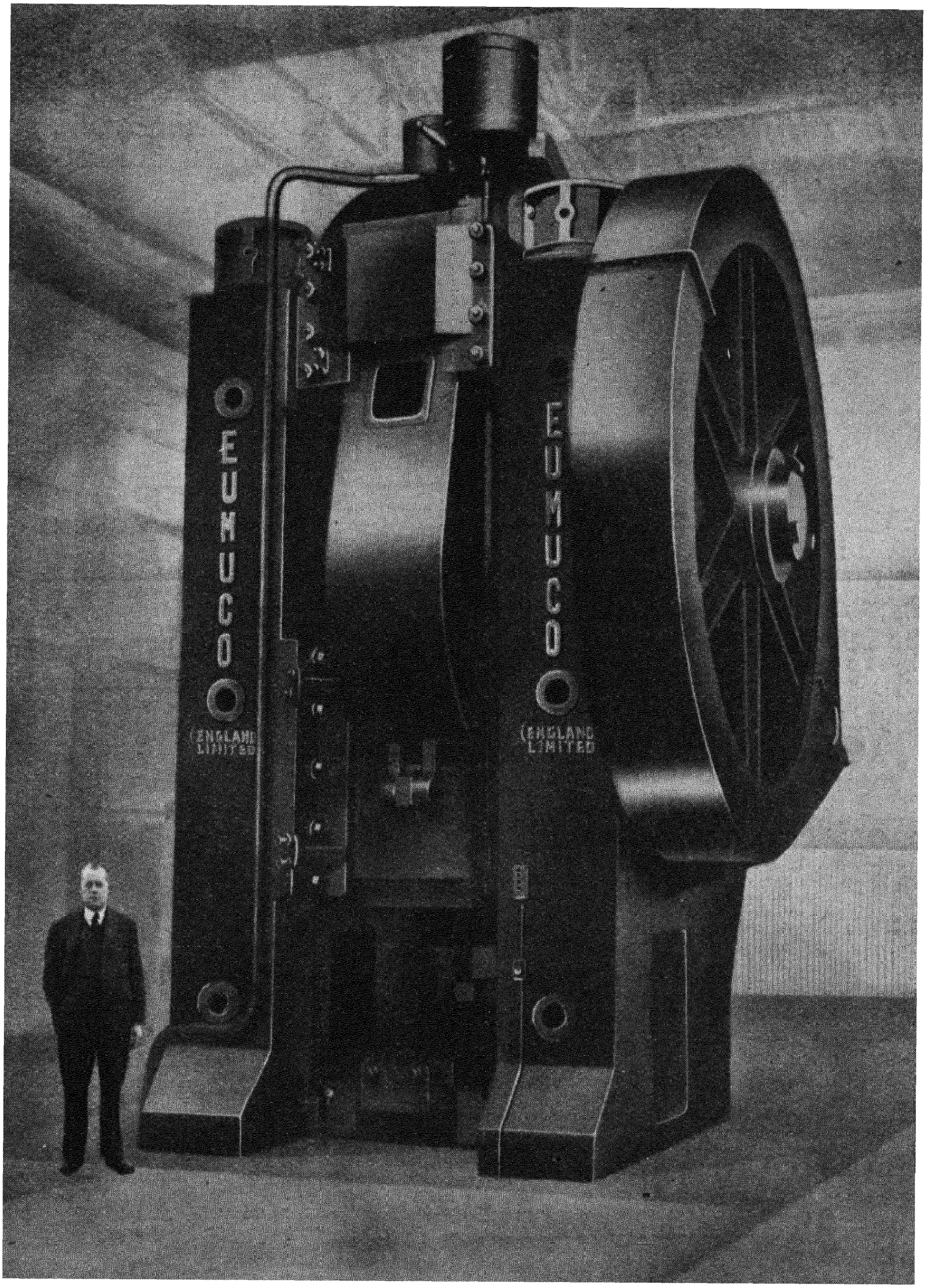


Fig. 2.—4,000-TON "MAXIMA" HIGH-SPEED PRECISION FORGING PRESS. THIS MACHINE IS ONE OF THE LARGEST MECHANICAL FORGING PRESSES EVER CONSTRUCTED

(*Eumuco* (*England*) *Ltd.*)

In the heavier presses the clutches are usually of the single- or multi-plate type and in the lighter presses the rolling-key pattern is used. These will be described in detail later.

Power presses fall into two broad groups: (1) Open-fronted, (2) Double-sided. The varieties which occur within these two main divisions are large, but generally speaking a press falls within a definite subdivision as indicated below.

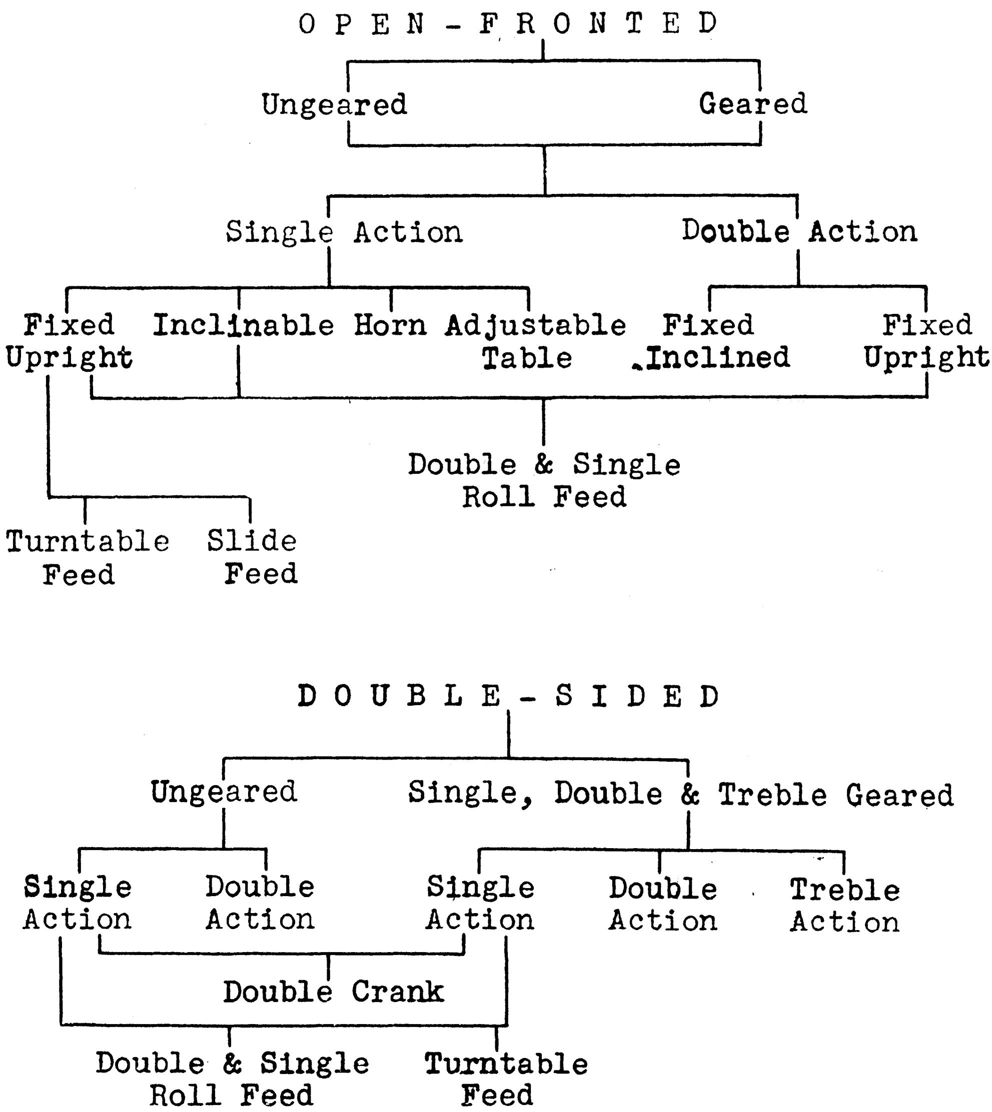


DIAGRAM SHOWING THE CORRELATION OF VARIOUS TYPES OF POWER PRESSES

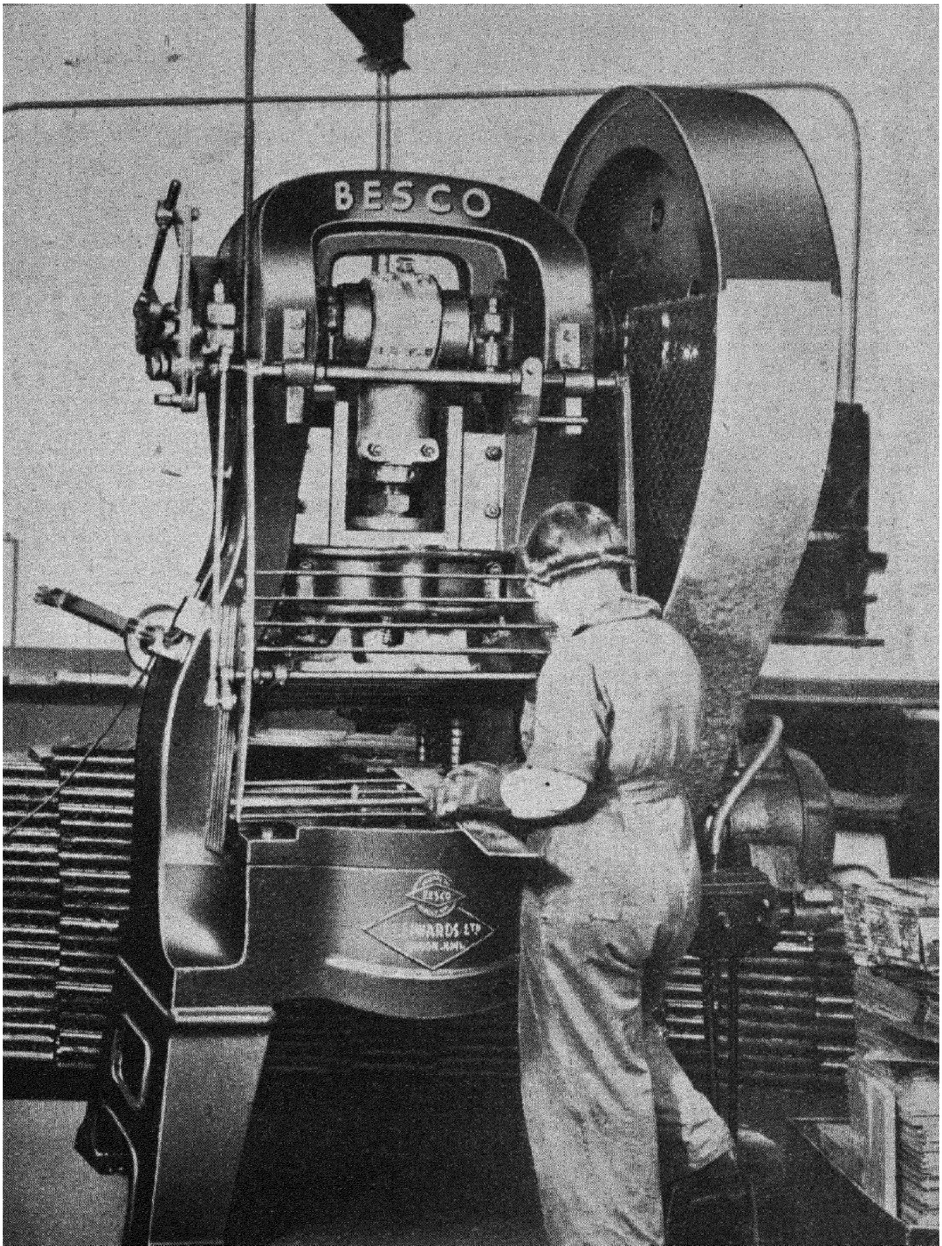


Fig. 3.—Double-sided power press, 75 tons pressure
(*F. J. Edwards Ltd.*)

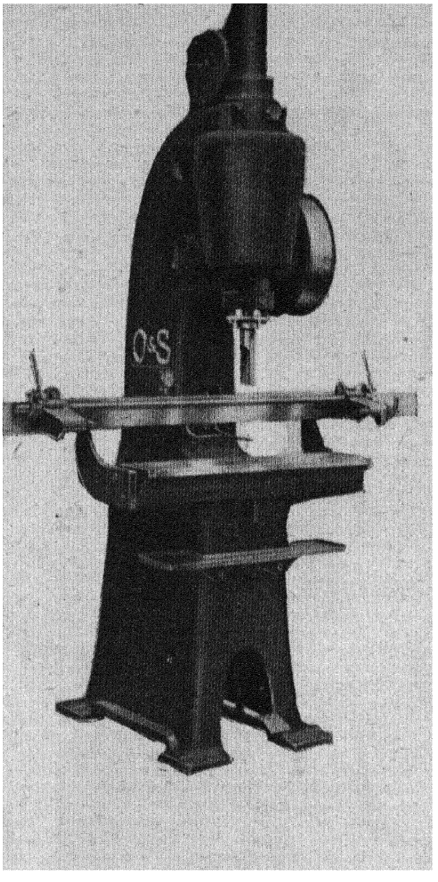


Fig. 4.—POWER STRAIGHTENING PRESS
(*Oldfield and Schofield*)

The type of machine shown on the left is employed in almost every branch of engineering, notably the automobile and aircraft industries, for straightening nickel-chrome and carbon-steel bars, shafts, etc., before and after heat treatment.

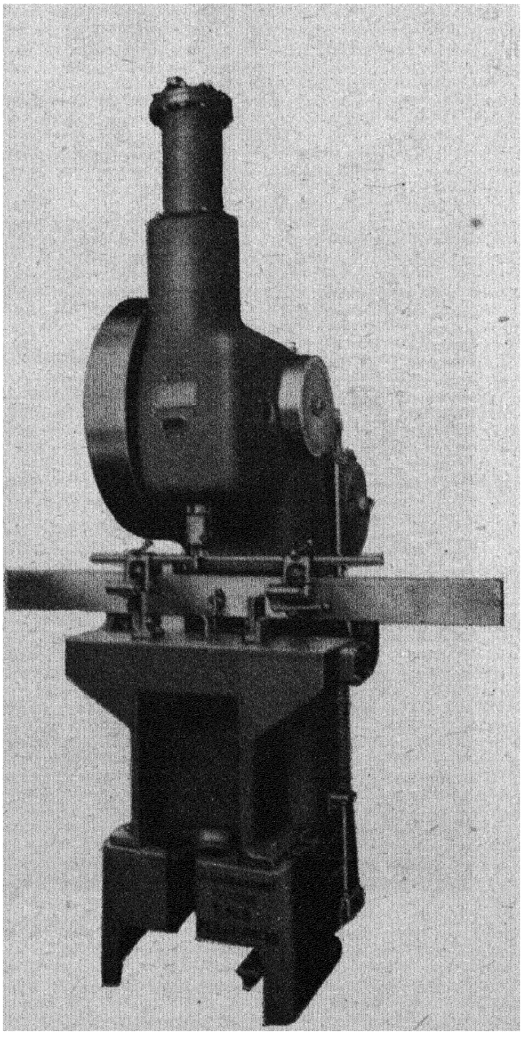


Fig. 5.—A 10-TON MOTOR-DRIVEN STRAIGHTENING PRESS
(*Jackson & Hunt*)

These machines are used extensively for straightening either hardened work or material in the black before turning, and if necessary straightening can be carried out to extremely close limits.

Open-fronted Presses

Open-fronted presses can be either direct drive or geared, and either can be of the single-action or double-action type.

The single-action open-fronted presses can be fixed or inclinable ; they can be designed specially as punching presses or they can be used as horn presses. The double-action presses, although usually fixed upright, are also inclinable.

Open-fronted presses are so called because the frame is designed with an open throat at the front, thus allowing sheet or strip metal to be fed to the tools. They are essentially " C " frame presses. They are made (*a*) as small bench presses, (*b*) as small units bolted to a stand, (*c*) with a one-piece frame which is bolted to the floor, (*d*) as an inclinable machine, (*e*) with a fixed table, (*f*) with a movable table, (*g*) as a bar or horning press. When the press has a fixed table tie-bars are often fixed in front to prevent the frame springing when the machine is working near or at its full capacity.

These presses are extensively used for small and medium-sized work, performing such operations as blanking, piercing, notching, beading and forming. With suitable pressure devices to control the metal as it flows, they are quite well able to perform cupping and raising operations.

The inclinable type has obvious advantages where high speeds are involved, and it is obvious that where a machine is making, say, 250 strokes a minute, clearance of the work is important. In order to accelerate this clearing, compressed air is sometimes used to sweep the finished work into the collecting bin.

Double-sided Presses

When used on heavy work, there is a tendency for open-fronted presses to spring open at the throat with heavy loads ; for presses from 75 to 100 tons it is usually better to use the double-sided type, in which the press frame is in the form of a closed arch. The work is fed to the tools through the arch, and sheets and strips are passed from back to front.

In the heavier types of double-sided presses the frame is built up of four pieces, that is, the bed, the two sides, and the bridge at the top, and these parts are keyed together and held rigid by tie-rods, which are heat-shrunk into position. This procedure results in great rigidity, for the tie-rods are expanded (simultaneously, if possible) by heating and the end bolts pull home tight. It follows, therefore, that when the tie-rods contract by cooling extreme tension is placed on these rods.

Bench Presses

These small power presses are built in a wide variety of sizes and styles and are now largely used in place of hand presses for light operations on

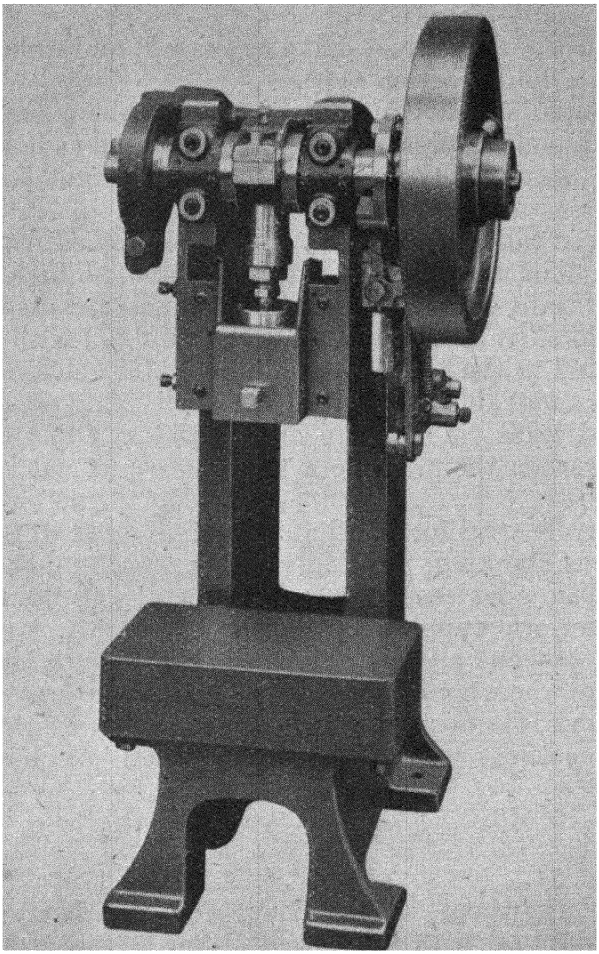


Fig. 6.—TYPICAL MODERN BENCH PRESS
(*Lee & Crabtree*)

sheet metal. They are either fixed or inclinable; some are arranged with horns, others with a high die space for operating sub-press dies; and yet others with long flange sides. They are rapid and easy to operate, a treadle clutch controlling the ram, leaving both hands free. Bench presses may be fitted with all types of automatic feeds. They can, of course, be equipped with an iron table and legs instead of being mounted on a bench.

These bench presses are suitable for a large variety of light work, for punching, blanking, forming, piercing, riveting, bending, and assembling, and their applications include the manufacture of buttons, light jewellery, watches, lamp burners, sewing machine and typewriter parts, electrical equipment, toys, and novelties. They vary in weight from 250 to 1,000 lb.

Upright Open-front Presses

In dividing presses into two main types—open-fronted and double-sided—the broad characteristics of the open-fronted class have been given as rigidity and accessibility to the work being done. Rigidity in the " C " frame is attained by the use of front stay rods, which can be removed if the work demands it. The table or bed is usually slotted so that bottom bolsters or dies can be fitted. The slots are planed to ensure that the die holding-down bolts take a proper bearing and that the dies remain fixed in their true position.

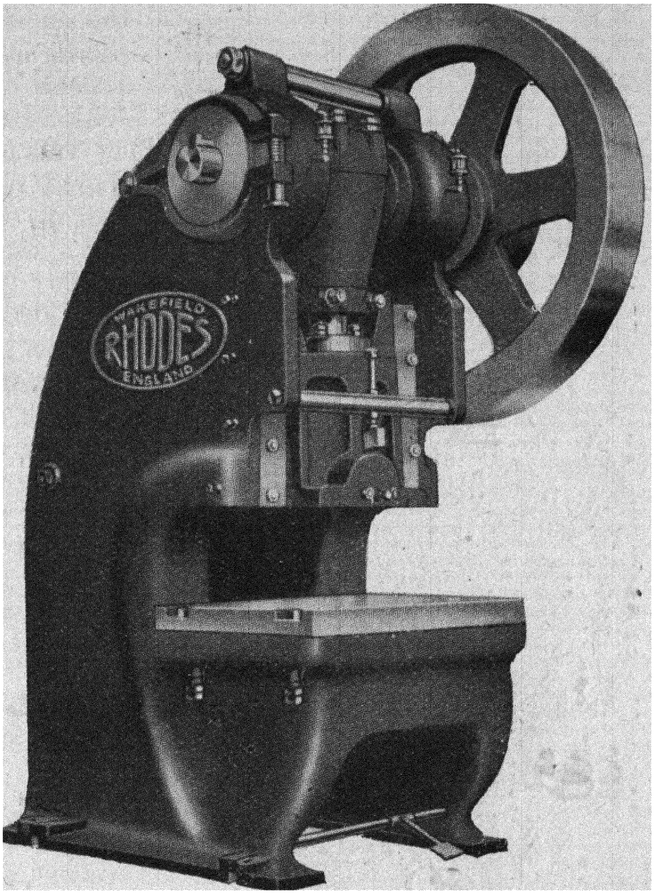


Fig. 7.—A TYPICAL OPEN-FRONTED PRESS
(*Joseph Rhodes & Sons, Ltd.*)

These presses are used for cutting out blanks from sheets of steel, brass, copper, tin plate, aluminium, etc., and for stamping these materials into a variety of forms. Another use which offers a wide field of operation for these presses is that of working combination tools. This design of tool is largely used for cutting and raising articles of thin material in one stroke of the press. In this way an operation is saved, as only one handling of the metal is necessary and the operator is entirely freed from the necessity of placing his hands under the die, since the material is gripped on either side of the cutting and stamping part of the dies. Any tendency of the blank to slip in position is obviated, since directly the blank is cut out and while it is being formed, it is gripped between the working face of the cutting punch and the pressure ring.

In the case of combination tools as illustrated in Fig. 8, the sheet of metal from which the article is made is placed over the die B. The punch A descends and cuts out and immediately grips the cut blank on the pressure ring C, which then descends, putting pressure on the rubber buffer. The outside portion of the blank is then drawn over the block D by the recessed inside of punch A, and the pad-piece E indents or letters the article if necessary, at the bottom of the stroke. The top knock-out F extracts the lid on the up stroke, while the scrap sheet is stripped off the punch by the stripper G. H shows the finished article (in this case a round box lid) ready for removal.

Cushions working under air or hydraulic pressure are largely used in

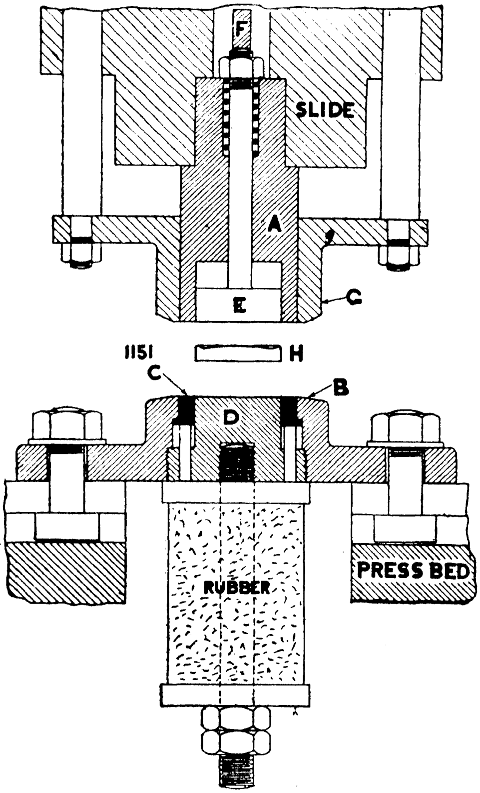


Fig. 8.—COMBINATION TOOLS

the same way as the rubber buffer shown in the example, enabling articles of considerable depth and complexity of form to be made.

This type of press can be either geared or ungeared. The frames are of tough, close-grained cast iron, the outer parts being of quality forged steel. They are built in a wide variety of sizes and designs, giving pressures of from 5 to 100 tons.

Built-in steel presses capable of exerting a pressure of 200 tons at the bottom of the stroke are made, and are suitable for heavy punching, cutting out and pressing steel plates. In such presses, within the limit of their capacity, embossing of metal plates can also be carried out.

Inclinable Open-fronted Presses

Like the fixed upright type, inclinable open-fronted presses are built in a wide variety of sizes and designs, with pressures of from 5 to 75 tons. They, too, are general utility machines, well adapted to the needs of manufacturers of sheet and metal goods. They are suitable for nearly every type of blank cutting, perforating, forming, bending and combination die work in brass, copper, aluminium, tin, light gauges of steel, etc. They are of massive design, built in close-grained, tough cast iron, strengthened with removable tie rods to prevent springing, so that they retain their accuracy through a long life. The fact that the body of the press can be set in an inclinable position is useful where combination dies are used, or wherever work is discharged from the top of the die, so that the finished product can slide by gravity into a container at the back of the press. Press manufacturers fit gearing to order for working comparatively thick material. The maximum inclination in these presses is 45°, with intermediate angles.

For mass production, where an article or part has to be produced in very large quantities, these presses are very useful, and in this repetition work a greatly increased rate of production can be obtained by employing automatic or semi-automatic feeds of the single- and double-roll type, dial feeds, etc. Rolls feeds are used for feeding strip metal from reels, dial

feeds for handling partly completed shells and parts which must be placed under the die separately ; but there are a number of feeds of a more or less special nature which can be applied to meet particular conditions.

Adjustable-bed Presses

These presses are very versatile machines in the light category which meet a large variety of needs. With the table in place they may be used for any of the short, medium, or long stroke work such as blanking, piercing, forming, bending, and for wiring, with the advantages of the gap type of frame for convenience and also of the adjustment in the table which makes possible the use of dies varying greatly in height. The table is easily swung to one side, leaving the face of the press frame clear for other uses.

Side-wheel presses with adjustable beds are built geared and ungeared in the larger sizes which weigh up to 20 tons. Wiring frames and slide plates for the use of deep wiring dies can be used with any of these presses ; other modifications include duplex folding and seaming presses with a horn for the manufacture of tin cans, lock-seamed pieced tin, black iron and similar work. There are also Double-horn presses for closing both seams of square cans simultaneously.

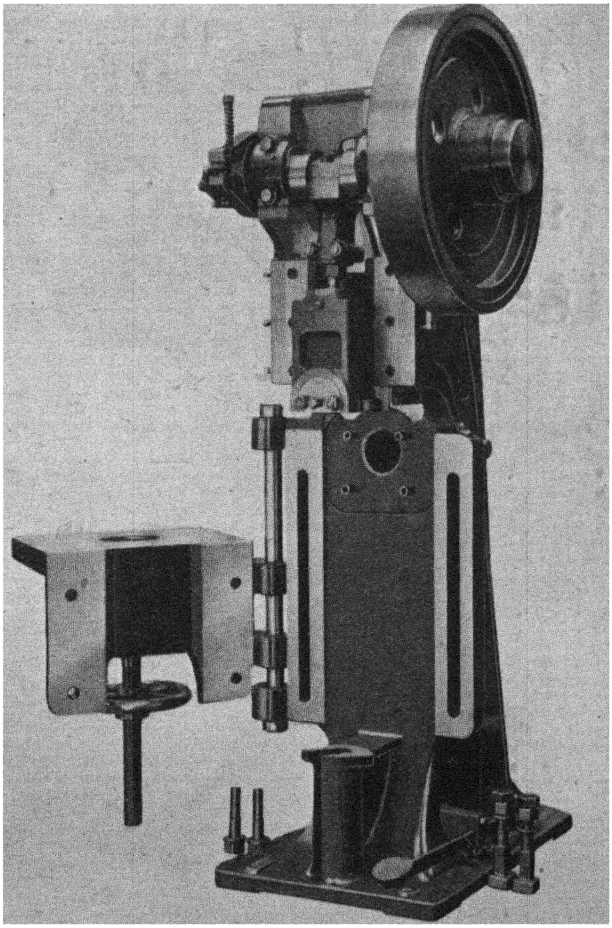


Fig. 9.—ADJUSTABLE-BED PRESS

(*Lee & Crabtree*)

End-wheel adjustable-bed presses are similar to the side-wheel type, but they have a special application where shorter stroke work and more heavy punch press work are involved. With the table in place they can

be used for blanking, forming, punching, riveting, stamping, or assembling operations, with the conveniences of the gap-framed construction for handling strips and odd shapes together with the advantages which go with the adjustable die space in dealing with variations in the height of dies. With the table swung aside and the horn in position, sealing, punching, and riveting operations can be carried out. Boiler-makers' presses, with depth of throat up to six feet, are made for perforating and for setting down body and head rivets on tanks, kitchen and bath boilers, etc.

Horn Presses

These are light, upright, open-fronted presses having no work-table but a " horn " or mandrel of solid metal which fits into the press frame. An adjustable-bed press, as has been said in the preceding paragraphs, can be arranged so that the bed is swung clear and a " horn " fitted.

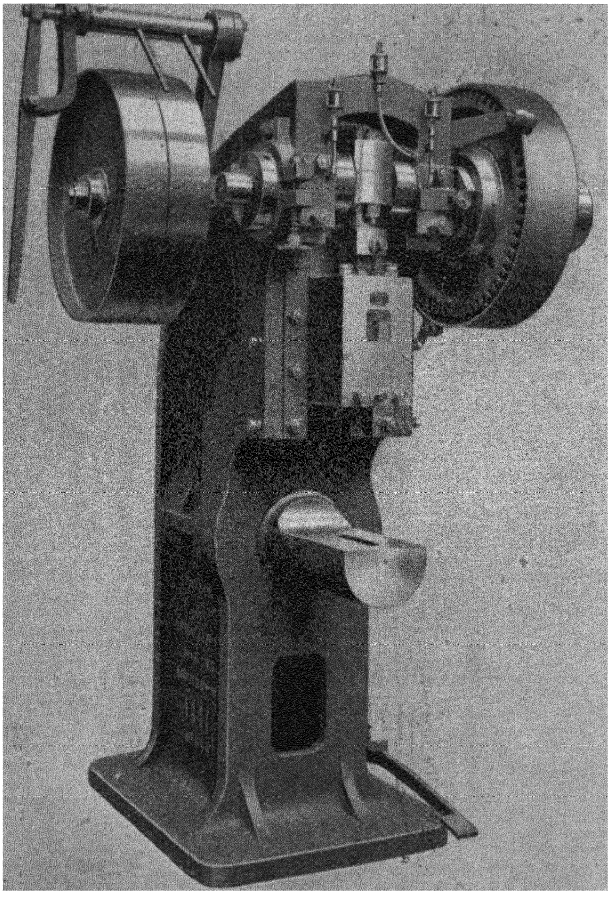


Fig. 10.—Horning press

(*Taylor & Challen*)

These presses are widely used for grooving, folding, wiring, and seaming, particularly for closing the side seams of drums and canisters. The horns themselves vary widely in size according to the requirements of the work to be handled, and run from a fraction of an inch to several inches. As regards their general construction, they follow the same lines as the open-fronted and adjustable-bed presses.

Double-sided Single-crank Presses

In the lighter types of presses falling within this category, the arch type of construction is most appropriate, the body being cast solid of close-grained

iron. They are either geared or ungeared, and apart from the cutting out, drawing, bending, stamping, and pressing of metals, they are used, with gas-heated dies, for pressing synthetic plastic powders into the multiplicity of shapes required in the wireless industry, for telephone parts, for electric apparatus, containers of every kind, etc. Some machines " dwell " at the bottom of the stroke to give the pressed material time to set to shape in the dies.

Double-sided Built-up Single-crank Presses

To stand up to the heavier strains set up in such work as pressing brake drums, clipping drop forgings and, in general, on heavier duty work, the solid casting frame is built up, the four components being the bed, the two side uprights and a top cross supporting piece, the whole being bolted together and then brought under a rigid holding stress by tie-rods shrunk into place. Such presses may be directly driven, but they are usually geared. In the heaviest class the frame is of steel and is double-geared with two sets of reduction wheels between the flywheel drive and the crankshaft gearwheel.

A press of this type, capable of exerting a pressure of 1,000 tons, will cut out a blank of mild steel in the cold, 8 in. in diameter and 1 in. thick.

If the width between the upright in the frame exceeds 40 inches, double cranks are employed. The 1,000- and 2,000-ton presses have gearwheels at both sides of the frame.

Double-sided Double-crank Presses

A complete range of machines in this class is available in innumerable standard designs weighing from 2 to 600 tons, with practically any crankshaft diameter from 3 in. to 21 in., with almost any width between the uprights from two feet to twenty-seven feet. They are open back and front and the numerous sizes in which they are made permit the handling of all types of material up to heavy steelplate and, with die cushioning in the bed, the same presses can be employed for a considerable range of drawing and forming work. Many modifications from the standard patterns have been evolved for special purposes.

The applications of these presses include the manufacture of automobile bodies, running-boards, fenders, rear axle housings, armature discs and segments, large pierced tinware, boiler covers and bottoms, steel wagon parts, metal coffins, steel stoves, etc. They can also be used for hot and cold forgings. They are very suitable for multiple gang punching, and also for perforating and operating several dies, where such work requires a series of operations one after the other, or for operating duplicate dies in gangs. Presses of this type are directly driven, single-geared, double-geared, and triple-geared, depending on the size of the unit. On the very large presses twin gears are used and a friction clutch.

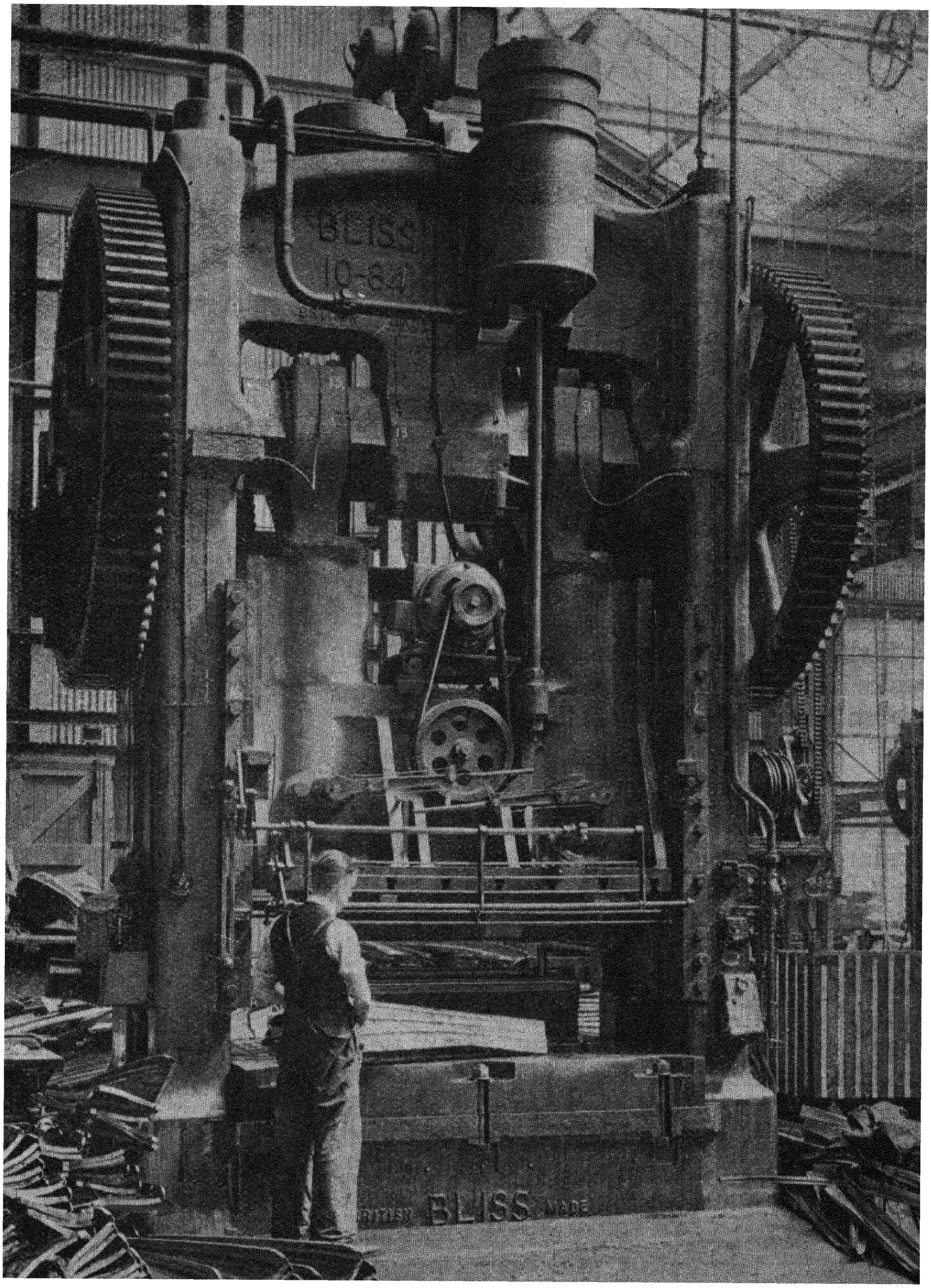


Fig. 11.—Double-crank single-action press manufacturing motor-car running boards

(*E. W. Bliss (England), Ltd.*)

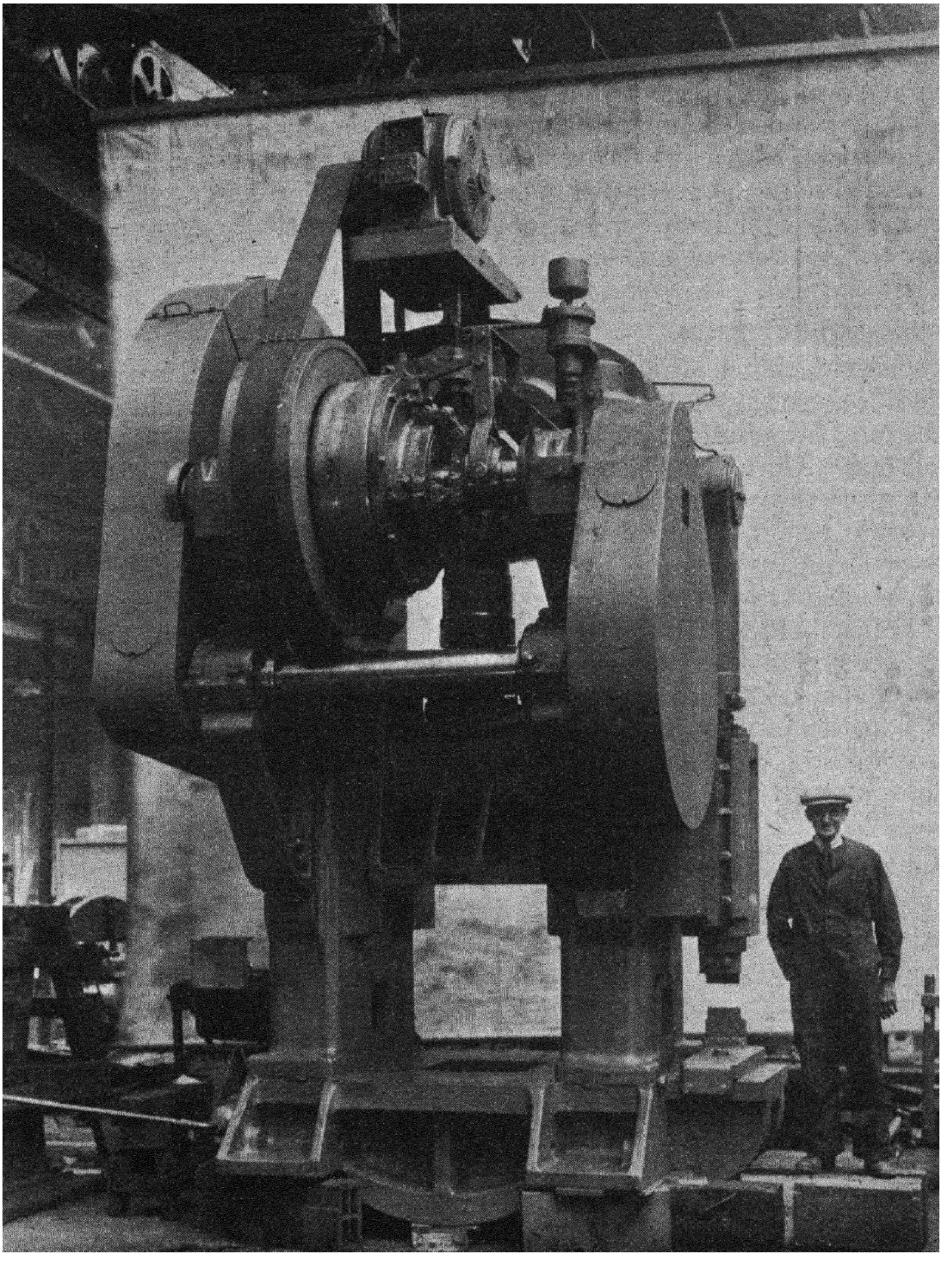


Fig. 12.—550-TONS TIE-BOLT TRIMMING PRESS
Rear view, showing clutch.
(*B. & S. Massey Ltd.*)

Some makers furnish electric push-button control with arrangement for continuous running, inching, stopping and starting at the top centre automatically, or at any part of the stroke. Usually there are two buttons for each operator, so placed that the hands are away from the slide before the press will operate. An additional aid in preventing accidents to both the operator and the die is the fitting of a single tripping device which can be attached to any of these presses when fitted with a positive clutch. A second engagement of the clutch is impossible unless the operator first removes his foot from the treadle and again depresses it for the next engagement.

Double-action Presses

These machines are for drawing operations and similar work and are so called because they have two slides, the outer gripping the metal, while the inner one, the plunger, performs the drawing. These two slides or rams work one within the other, the inner ram being connected to the crankshaft while the outer ram is operated either by cams on the crankwebs or by toggle levers. Cam drawing presses serve lighter duties, the toggle presses being used for heavier work. Both the open-fronted and the double-sided type of frame construction is employed with these machines.

"Blankholder slide" is a term used for the outer ram, which aptly describes its function, for in drawing it is this slide which first descends and exerts a constant holding pressure on the blank, followed by the inner ram, carrying the top punch, which pushes the metal through the die. This blank-holding slide usually has a stroke about half that of the punch slide.

Double-action Cam Drawing Presses

Cam presses cover the field for double-action presses up to and overlapping the smaller sizes of toggle presses. In general, the cam press is faster on account of the fewer moving parts and more accurate for cutting dies than the toggle press. It is, however, less powerful, and limited, regarding depth of draw, to size of cams which can be used successfully. In its own range of work it is the most satisfactory press for double-action operations, whether it is holding and drawing, blanking and cupping, cutting, drawing and stamping, or embossing or redrawing and piercing. It also has distinct advantages over the single-action presses equipped with a pressure drawing attachment both in range and convenience, and in the fact that the pressure exerted by the cams is absolutely uniform during the draw instead of building up as in the pressure drawing attachment when the springs are compressed.

These presses have the regular blankholder adjustment and the cams and friction rolls are made of tool steel carefully hardened and ground, the cams being fitted to the cheeks of the shaft. The larger sizes are built

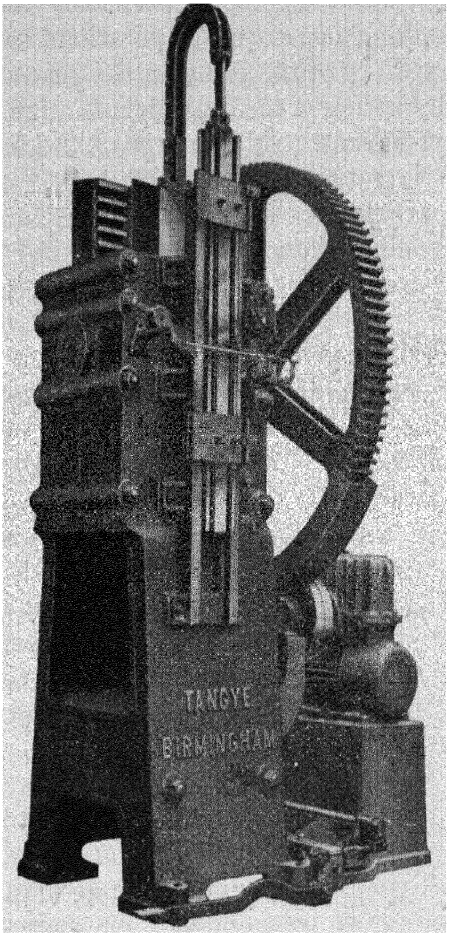


Fig. 13.—DOUBLE-RACK DRAWING PRESS

On the left is shown a double-rack drawing press generally used for shell-case drawing. Two punching racks are provided. While one is descending and drawing the case, the other is lifting ready for the next draw. The presses can be fitted with the usual gear reduction, or with a worm reduction.

(*Tangyes Ltd.*)

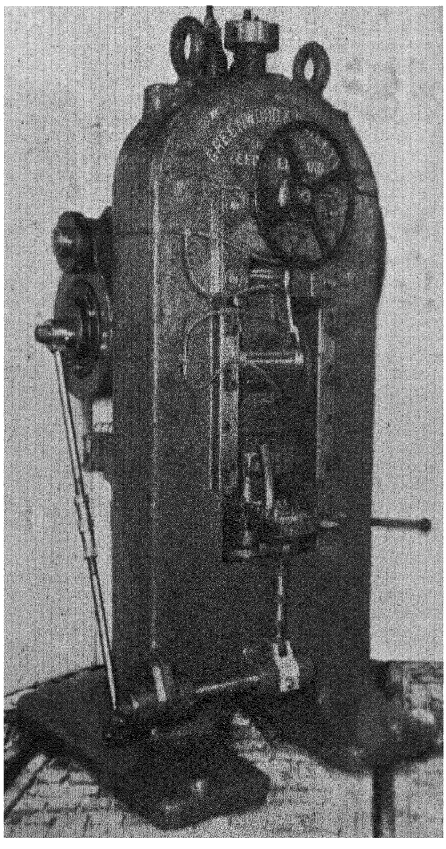


Fig. 14.—THE II RIGHT SHOWS A TOGGLE-OPERATED COINING PRESS, MANUFACTURED BY GREENWOOD & BATLEY

both as flywheel and geared presses, the geared type being preferable for working the heavier metals. Where blanking and drawing operations are being performed near the limit of the capacity of the press on the geared type, tie-rods are advisable to prevent any spring in the frame which might cause undue wear on the cutting edges of the dies. A lever type of knock-out is readily arranged connected with the return cam arm.

For economic production of small articles in large quantities, cam presses are frequently equipped with feeding devices of various kinds, depending on the particular article to be produced.

Toggle Drawing Presses—Single- and Double-crank

Double-action single-crank toggle drawing presses are used for shallow and deep drawing and the forming of round, square, or irregular shapes, as well as for double-action and redrawing work. Toggles, operating the outer slide, relieve the crankshaft of the blank-holding strain. Rugged simple construction is an essential if the machines are to operate with a minimum of wear in standing up to the strain of dwelling on the draw.

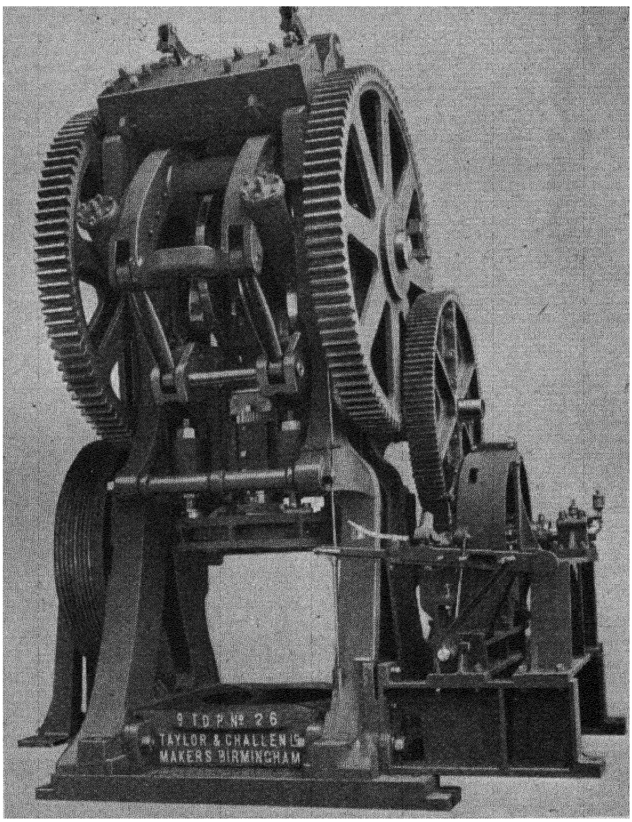


Fig. 15.—Heavy-duty double-crank toggle drawing press

(*Taylor & Challen*)

These presses are capable of drawing to greater depths than either double-action cam presses or single-action presses with spring pressure attachments, the blank-holder pressure being practically uniform instead of building up as the springs compress. The "dwell" during the drawing period is also very effective. For double-action reducing work, single-crank toggle drawing presses are built with considerably longer strokes and increased distance from bed to slides. Their more common uses are

shallow and deep drawing, forming of round, square, and irregular shapes, and combination blanking and drawing. Cooking utensils and kitchen ware in tin, enamelled ware, and aluminium are largely made on them. Presses for aluminium run faster than those working other metals. The smaller machines find a wide application in brass and iron hardware, apart from cooking utensils, steel gongs, electrical parts, square and round boxes, lamp shades and reflectors, etc. The field of the larger machines includes brake drums, dish pans, wheel-barrow trays, automobile parts, etc.

On large-size toggle presses it is usual to employ two cranks instead of one and separate motor adjustment to the slide mechanism has become standard practice on the really heavy presses, which can shape whole sections of automobile bodies. The high cost of these big machines can only be borne where very large numbers of motor-car bodies have to be produced. Remote control by either electric or pneumatic devices is installed and cushioning and load-equalising cylinders are often incorporated in the action.

In the forming and stretching of metal requiring heavy blankholding pressure which frequently exceeds the drawing pressure, double-crank toggle drawing presses have obvious advantages, since the blankholding pressure is carried by the straightened links and steel rockshafts and not to the crankshaft directly.

Four-point Double-action and Triple-action Presses

In shaping whole sections of automobile saloon bodies and in aeroplane work the difficulty of ensuring even settling of the pressure plate, and of avoiding tilting of non-symmetrical tools in presses of large size, is a very real one. These two difficulties have been met by using pressure-plates loaded by pins controlled by a number of separate or fluid pressure rams, and in the case of the crank-actuated presses under discussion by imparting movement to the ram by four separate cranks attached to its four separate corners. Some presses have a triple-action in which there is the usual blankholder slide for holding purposes and the inner, or plunger, slide for the first drawing or forming operation. In the bed there is a third slide operating independently, and this synchronises in its operation against the partly formed piece to complete the whole operation.

Crankless Presses

These are two- and four-point suspension presses which have been developed for the automobile industry. Crankless presses are dealt with elsewhere, and their construction is clearly described. They are built in a wide variety of sizes and widths to meet the needs of motor-car manufacture, for blanking, indenting, beading, piercing, and shallow forming operations in the production of relatively large work such as body panels, doors, fenders, running-boards, etc.

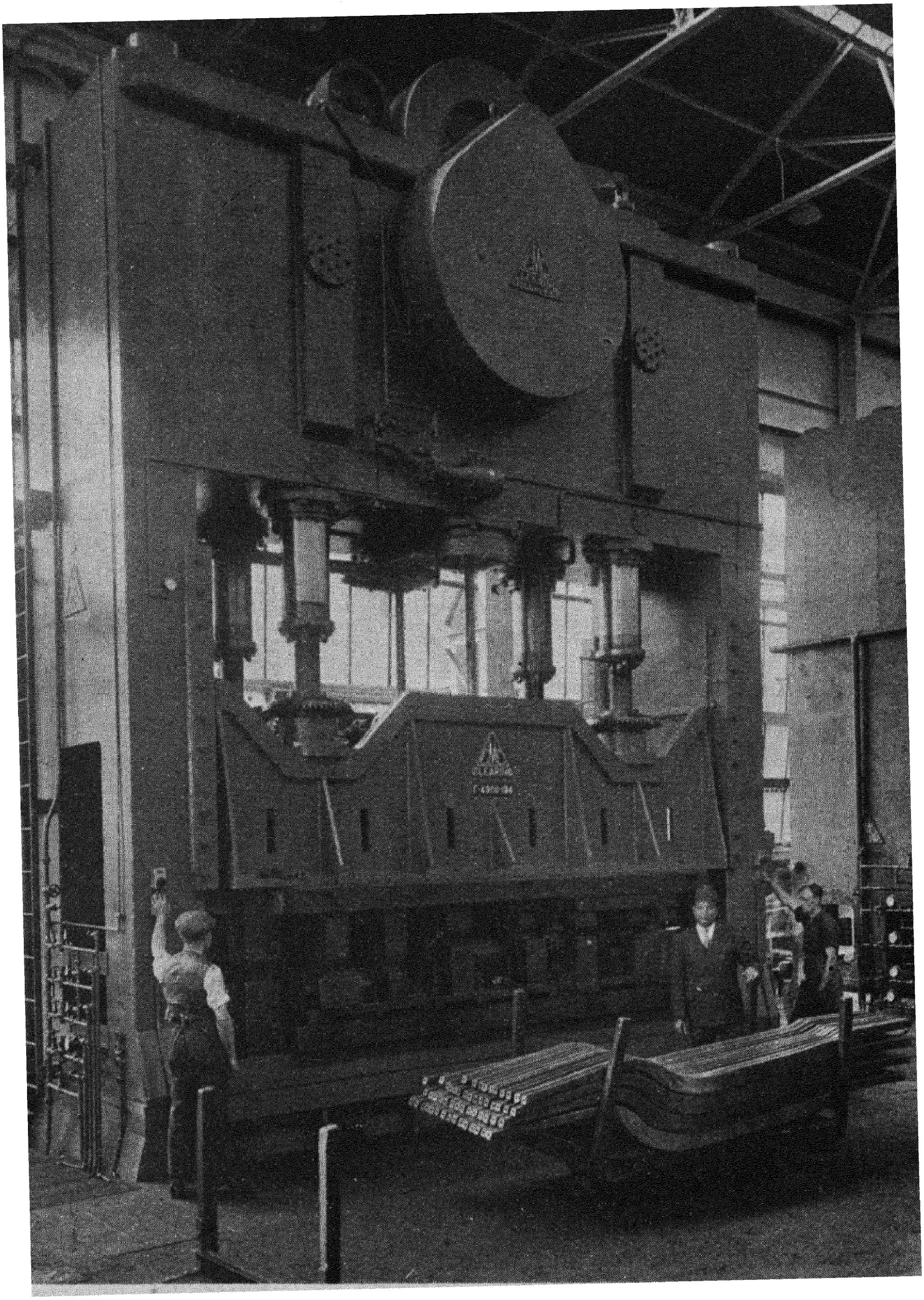


Fig. 16.—A "CLEARING" CRANKLESS PRESS

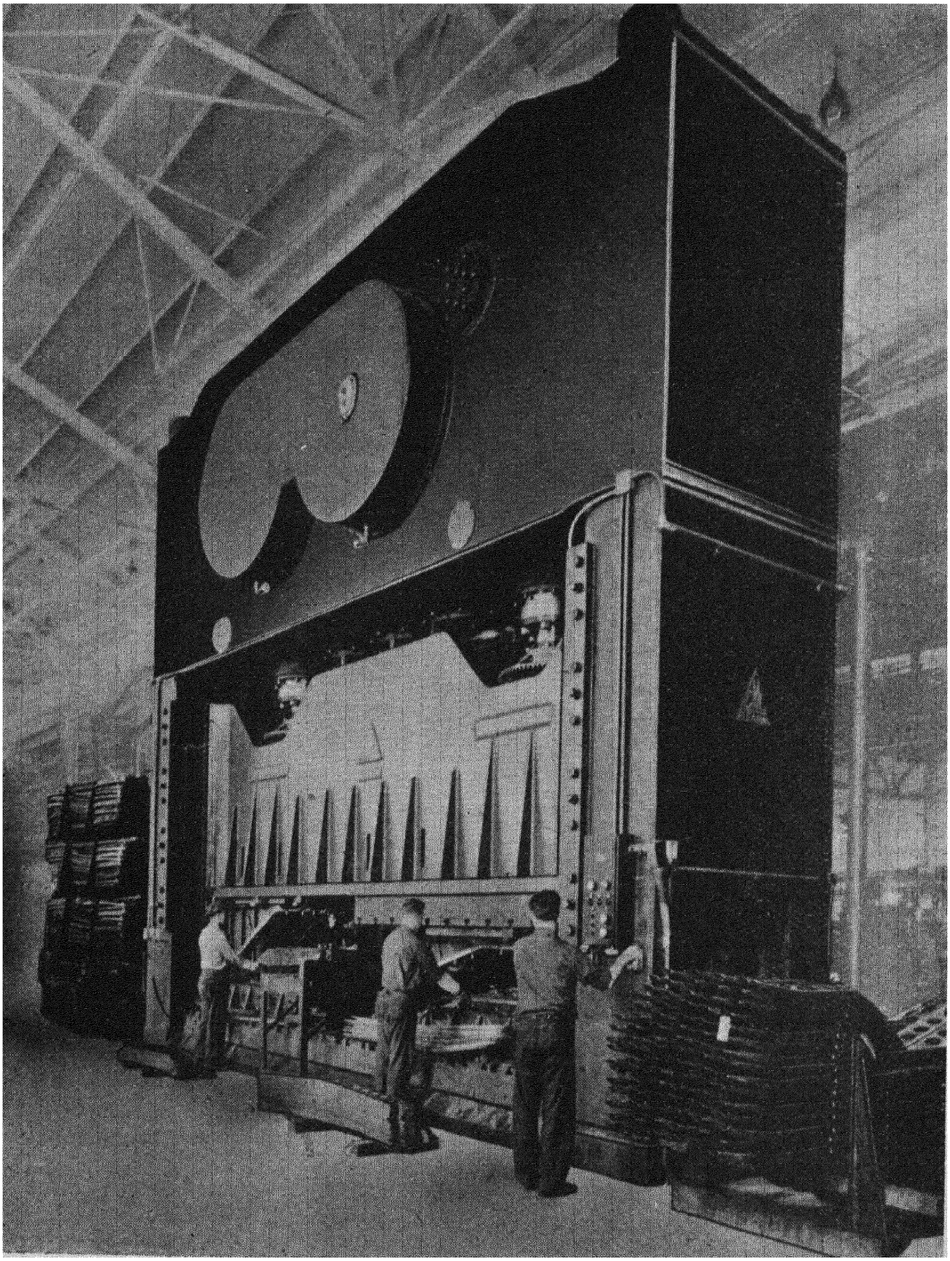


Fig. 17.—A "CLEARING" CRANKLESS PRESS OF 2,600 TONS CAPACITY MANUFACTURING SIDE RAILS FOR MOTOR-CARS

These mammoth machines have been evolved in America to cope with the mass production of automobile body parts. The symmetry of their design is shown in the illustration. In comparison with many presses of much lower power, they are models of simplicity.

The essential point of these presses is that the four-point suspension has the centre of pressure falling anywhere within a fairly large area in which the four points mark the four corners. This prevents tilting with the unbalanced loads met with in automobile work.

Coining and Embossing Presses

These are double-sided, knuckle-jointed machines. With the exception of extrusion work, they represent the highest stress reached in press work. The essential requirement is a slow, powerful pressure exerted during only a short portion of the stroke. For heavy stamping operations at the bottom of deep shells, long-stroke presses with strokes of 8, 10, or 12 inches or more, to meet the requirements, are used.

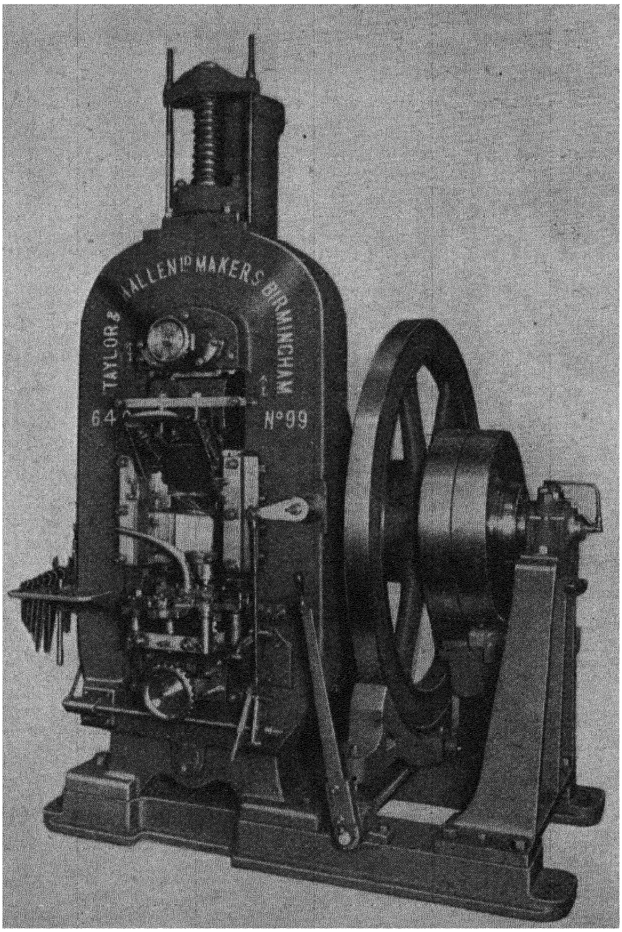


Fig. 18.—Modern type coining press

A knuckle-jointed machine, used quite generally for currency production. Revolving rollers in the knuckles, with forced lubrication and oil seal, obviate the risk of heating, always a difficulty with this type of machine. The rollers revolve when not under pressure. To coin a halfpenny, 76·4 tons pressure are needed, for a penny 109 tons, and for a half-crown 90 tons.

In order to give the necessary rigidity, the bodies or press frames are cast in one solid piece. In the larger sizes rigidity is achieved by using a four-piece steel tie-rod frame construction. The toggle links or arms are machine-steel forgings, except in the largest units, where dense steel castings are used.

In the largest presses of this type, which exert a pressure of 1,500 tons, forgings, drop stampings, and certain castings can be "coined"—that is, brought to size in their cold state

by pressure, within limits previously only obtainable by costly machining.

To " coin " within fine limits requires machinery outside the requirements of an ordinary power press in order that the three essentials—great pressure, accuracy, and high production—are attained. The frames are exceptionally massive and compactly designed to reduce deflection to a minimum, being further strengthened by high-tensile-strength steel bars. There must also be a minimum number of moving parts subject to compression and wear under load.

End-wheel or Punch Presses

In these machines the crankshaft runs from front to back, with the flywheel at the back. An eccentric at the front of the machine, working through a connecting rod and a bull screw, actuates the ram. These punch presses are specially designed to deal with work which cannot be effectively handled on either the open-fronted or double-sided type of design. They are made in a wide range from 2 to 120 tons.

They are particularly adapted for making fine accurate parts and heavy blank cutting, piercing, and perforating. End-wheel presses are suitable also for cold trimming of drop forgings, stamping, light embossing, and various riveting, bending, and assembling operations. Special machines of this type are much used in the manufacture of watch and clock parts,

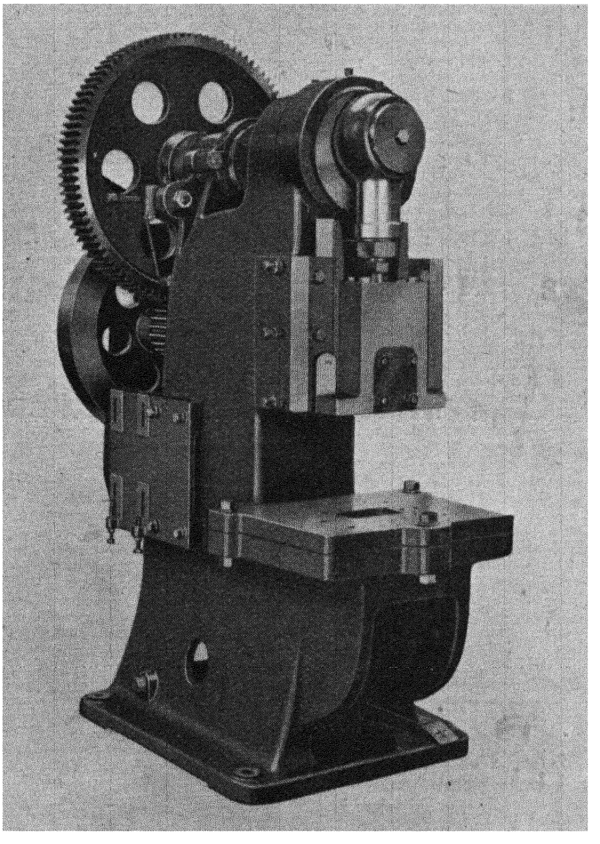


Fig. 19.—END-WHEEL PRESS

The chief application of end-wheel presses is in the mass production of small parts which must be stamped out within fairly close limits. No deflection in the dies is permissible, and the means by which this is achieved is obvious from the typical design revealed in the illustration.

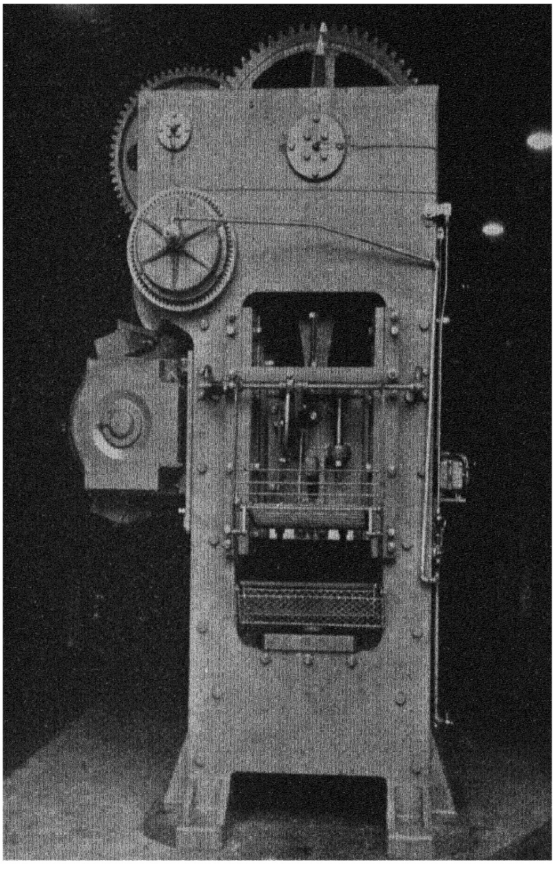


Fig. 20.—150-TON CRANKLESS PRESS

This press is of fabricated steel-plate construction, top ejector and combined pneumatically operated plate clutch and brake. The machine is constructed to ensure long die life between regrinds. It is specially suitable for heavy drawing work, forming, and blanking operations.

(*Horden Mason & Edwards Ltd.*)

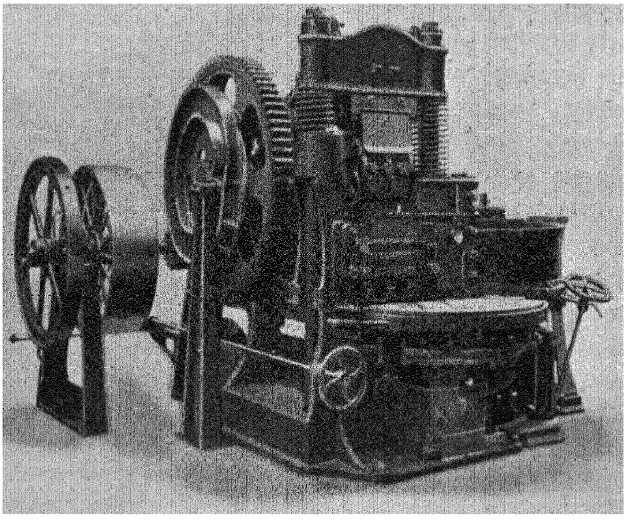


Fig. 21.—A ROTARY TABLE PRESS

As a brickmaking machine, this powerful rotary table press has a capacity of up to 3,000 bricks per hour.

(*Sutcliffe Speakman & Co.*)

jewellery, and similar small accurate work where quantity production of a quality article is essential; but they find their main application in the manufacture of hardware, typewriters, adding machines, sewing machines, locks, cutlery, electrical parts, etc. Manufacturers of these presses aim at producing robustness of framework so as to give the necessary rigidity for the long life of cutting dies.

Extrusion Presses

Extrusion presses are used for making collapsible tubes, battery cases, cartridge cases, etc. The metals worked are lead, tin, zinc, aluminium, and brass. The blanks are cut, or cut and formed, in multiple dies, six, eight, ten, or twelve per stroke.

Extrusion work, not excepting coining and embossing, makes the heaviest demands on power presses. This type of press work is old. In the modern sense it was being practised as early as 1870, but as far back as the eighteenth century preheated lead and tin were being extruded in screw-operated cylinders.

Plastic flow begins in a metal when the yielding point is exceeded. The flow resembles that of a viscous fluid. Most extrusion presses for the manufacture of collapsible tubes have short strokes, and the punch, after rising clear of the die, swings or slides forward to a position where the tube may be stripped off by hand or blown off by an air jet through the punch. As the pressure is applied the metal squirts up around the punch, which must be accurately centred.

The eccentric shaft, shrunk tie-rod type of press has been successfully used in this extrusion work. In one design the punch is brought to a stop just as it reaches the metal, and then accelerates and performs the extrusion at an almost uniform rate to give an even, uniform flow. Fast-moving eccentric presses used in the extrusion of large aluminium sheets have a capacity of 500 tons.

The basis of press selection in the extrusion of lead and tin tubes is about 60 to 80 tons per square inch, and as very little cooling or lubrication can be used, the heat generated is large and limits the operating speed to 40 to 45 strokes per minute. Rhodes presses are being used at much higher speeds than this, however, for extruding zinc battery cases from blanks at the rate of 70 per minute.

It should be noted that although the yielding point of a metal, say, zinc, may be 6 tons per square inch, it does not mean that the metal flows as soon as this limit is exceeded. Extrusion does not start until a pressure of 25 to 30 tons per square inch is reached.

Friction Screw Presses

Percussion screw presses were made in Birmingham nearly a hundred years ago, and used for simple pressing, then for coining, and later for steel stampings. They find their chief application in hot brass pressing work,

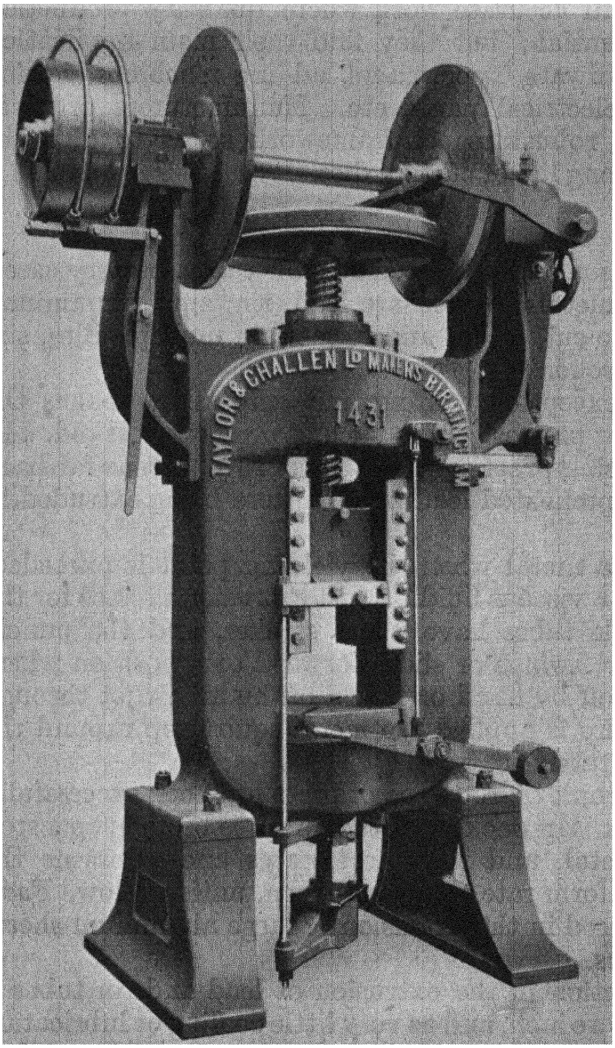


Fig. 22.—MODERN FRICTION-WHEEL PRESS

A rapid-working press, with high production rate, mainly used for hot brass pressing work, but also very effective for heading operations on steel bolts and aero-engine valves. The wheel is light and small and revolves at high speed. This machine has a long slide stroke, which gives the best results in brass pressing.

embossing and planishing, hot forging, medal striking, die sinking, and finishing operations on such articles as fountain-pen nibs, buttons, buckles, etc.

A fast-pitch screw actuates the ram instead of a crankshaft, and consequently they have a working stroke with a uniform velocity. The screw is connected to a friction drive at the top of the press, and this is driven by friction wheels, revolving in the same direction, on opposite sides of the disc. One contacts and makes the descending stroke and the other friction wheel makes the upward movement. The movements of the slide are controlled by a hand lever which is quite sensitive, and an adjustable stop is fitted so that either a light or a heavy blow can be given. The slide always returns to the top position when the hand lever is released.

These screw presses range from small units, exerting a pressure of 10 tons and running at 30–40 strokes a minute (diameter of screw 2 in.) to those with a screw 8 in. in diameter used for hubbing steel dies in the cold or hot state, for striking medals up to 7 in. in diameter.

The modern heavier belt-driven screw presses which exert pressure ranging from 50 to 200 tons have a cast-iron frame of very heavy section, reinforced by forged-steel tie-bolts, which are shrunk in hot.

Notching Presses

These machines find their widest application in the manufacture of electrical machinery, e.g. armature plates for motors, stator plates for motors and dynamos, rotor plates and segments. They are largely a speciality of the firm of Taylor and Challen, who produce a comprehensive range to meet the needs of the electrical industry. Notching presses are, of course, widely used in other directions, such as for cutting the teeth of circular saws. They vary largely with the class of work they have to perform—700 strokes a minute in the case of those designed for light work to 70 strokes per minute for heavier duties. Notching presses are also used for cutting teeth in sprockets for the cycle industry and for the manufacture of change-speed gears for cycles.

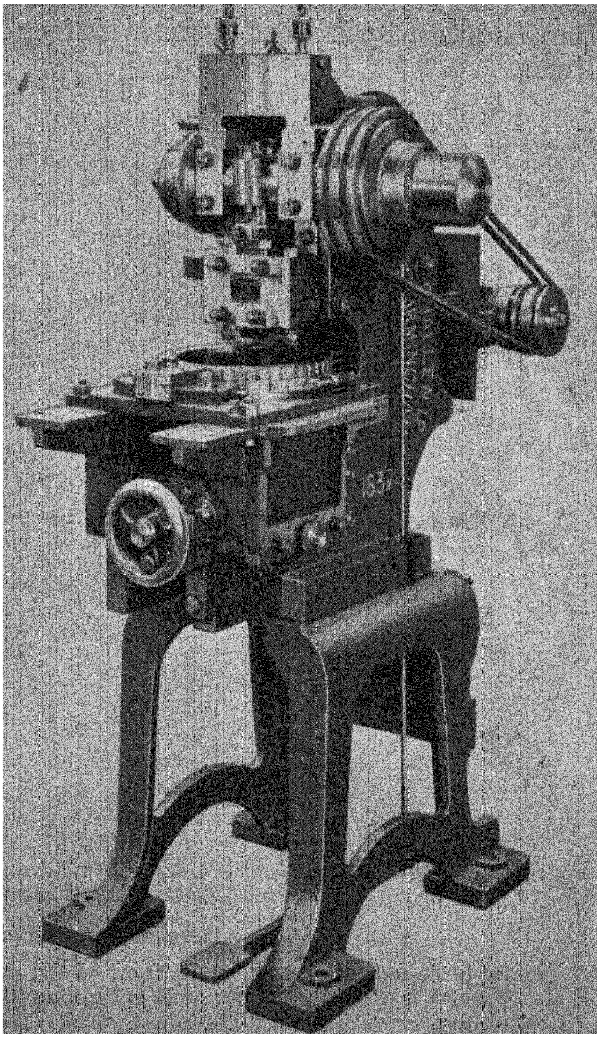


Fig. 23.—STATOR NOTCHING PRESS

Speed from 225 to 450 strokes per minute. Used for cutting stator plates. Smallest pitch-circle diameter $2\frac{1}{2}$ in., largest $11\frac{1}{2}$ in. Rotation of the plate being cut is obtained by means of a friction wheel, which is held by a stop bolt during the return stroke and during the punching operations. This stop bolt is adjustable to suit the starting-point of the notches in relation to the drawing keyway in the plates. The press has a table to take three sizes of carrier beds, which is sufficient to cover the whole range of diameters up to 14 in., outside diameter. This particular illustration shows a motor-driven press (motor is concealed behind), a countershaft giving the required variations in speed.

Bending or Folding Presses or Press " Brakes "

" Brakes " or bending presses are in a class by themselves. These are primarily heavy-duty machines used for bending, straightening, shearing, etc.

They are capable in their largest sizes of bending steel plate of $\frac{3}{16}$ in. thickness to a width of 80 inches. These dimensions imply rigid construction, and "brakes" are made in either steel or cast iron, reinforced against distortion by steel bars shrunk in hot.

Multiple Punching Machine

These double-sided, double-crank, double-geared presses are specially made for punching a series of accurately spaced holes in plates and sheet metal. General sizes are for piercing up to 48 holes in a length of 4 feet. They find their application in the manufacture of riveted containers and drums.

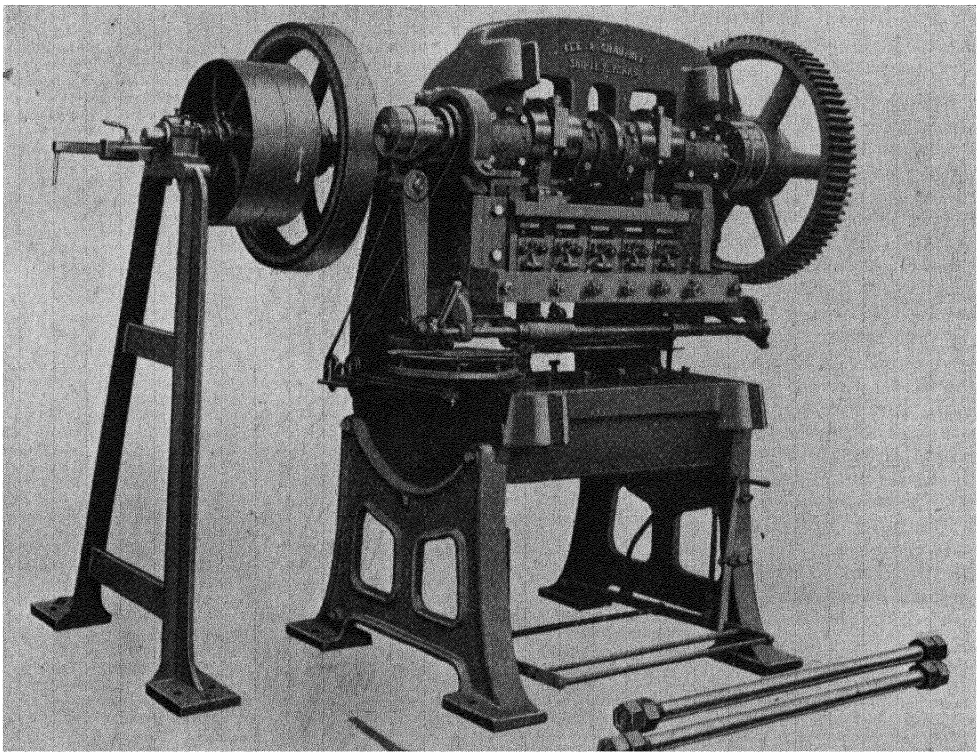


Fig. 24.—Multiple punching machine

The movable tie-rods are shown in the front of the press. They give the extra rigidity which is needed when the press is working to the limit of its capacity.

(*Lee and Crabtree.*)

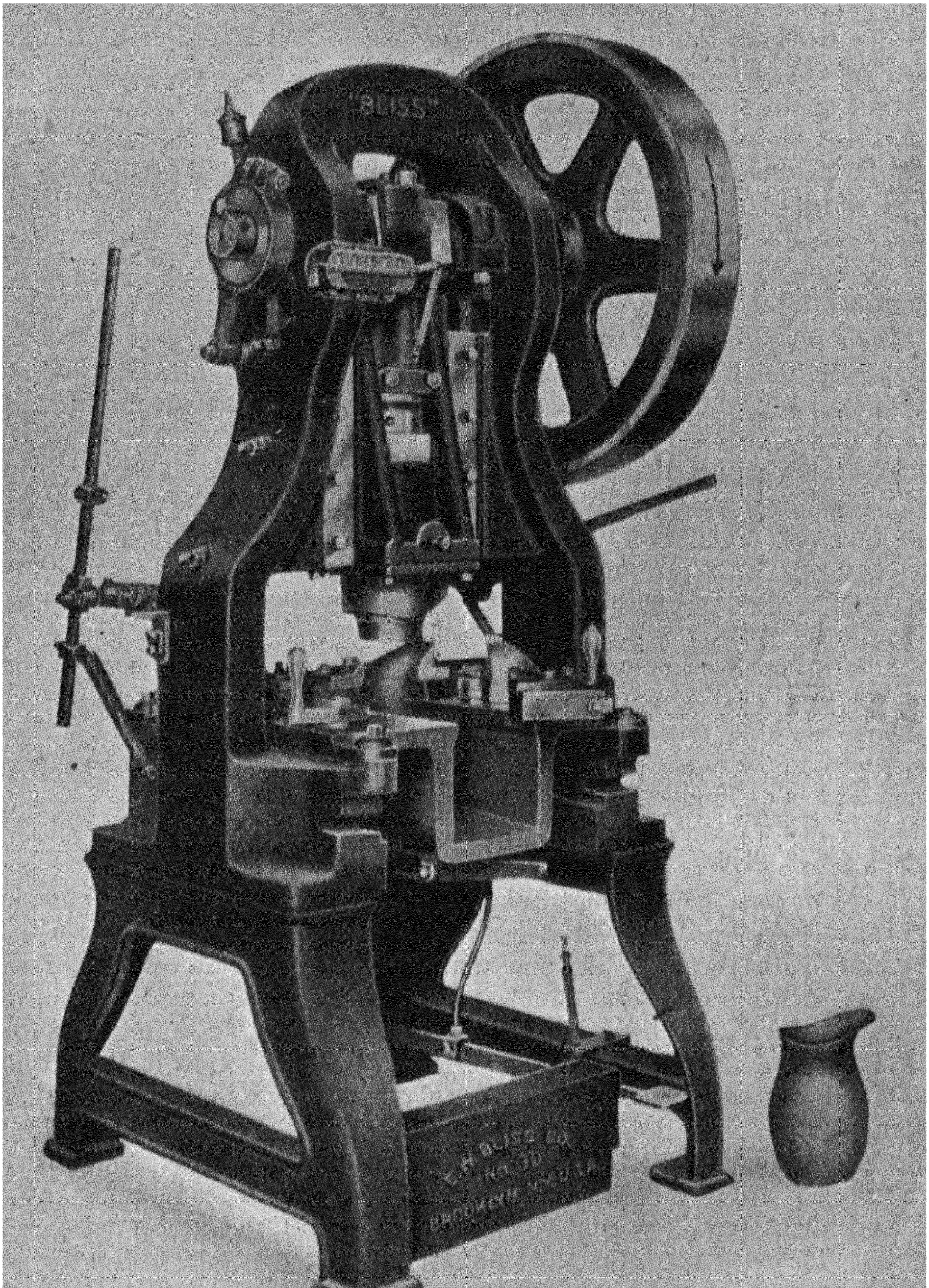


Fig. 25.—BLISS NO. 30 ARCH PRESS

(*E. W. Bliss (England), Ltd.*)

ARCH POWER PRESSES

The utility of the arch type of construction lies in the proportionately large area of bed and slide in relation to the shaft size and the advantages of the straight-sided type of frame in weight and rigidity over the corresponding gap-frame presses. The field for these presses is therefore mainly light large-area sheet-metal work; blanking, cutting, and trimming of large shapes; bending, shaping, stamping, and large-area lettering; general combination die work, spring drawing, cutting and stamping, etc.

Horning and Wiring Attachments

Arch presses are sometimes modified for special purposes.

In addition to the regular work of blanking, punching, stamping, etc., arch presses may be equipped with attachments for horning and wiring work.

For this purpose they are built with a removable front section to the bed which makes the opening in the bed available for the use of horning attachments, and sunken bolsters or frames having sliding plates for wiring dies. This, of course, considerably increases the range of work the press can do and will be found especially valuable in factories where space is limited.

All the best arch presses are built with solid cast-iron frames, machine-cut gearing, and forged crankshafts of high-carbon steel. The slide bearings are long, accurately fitted, and readily adjustable.

A number of these presses have been built with exceedingly high die space and very long strokes for special uses.

The Smaller Sizes

The work of the smaller sizes is mostly in comparatively light sheet metal as black iron and tin plate, the capacity of the presses increasing of course with the size. In the making of tinware or enamelled ware such as coffee pots, pails, buckets, and small pans and work of this character, the regular use of these presses is blanking, stamping, and forming of bottoms and bodies. With the removable section in the front of the bed, however, and horning and wiring attachments, they can be used also for closing the sides seams and wiring the edges. With other dies the same press is used for trimming the top of the pitcher previous to wiring. Arch presses are also used in making petrol and paint cans, and they can be used for stamping panels, tops, and ornamental designs or lettering in tin plate for other containers. The large bed area is very useful for large or awkward dies, for combination dies for blanking and stamping or spring drawing, or for blanking or forming any large or irregular shapes such as fire shovels, metallic shingles, discs or sectors, coal-hod bottoms, etc. They are also used in the manufacture of sewing-machine parts, electrical equipment, spoons, skate parts, large ornamental hinges, etc.

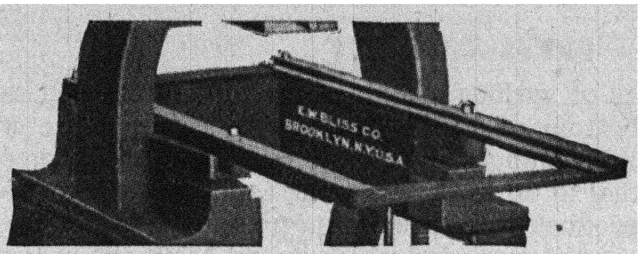


Fig. 26.—PLAIN WIRING FRAME

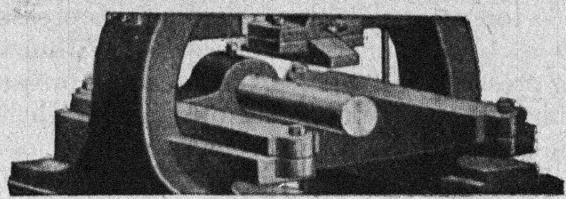


Fig. 27.—HORN FRAME FITTED WITH STRAIGHT HORN

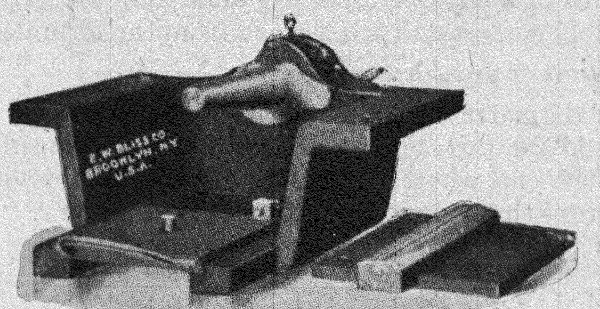


Fig. 28.—HORN FRAME WITH SUNKEN BOLSTER AND SLIDE PLATE COMBINED

The " Bliss " No. 30 Press shown illustrates the removable front section of the bed. This section is out and the press is arranged with a special sunken bolster and special split dies for wiring the top and spout of the water pitcher shown.

Fig. 26 illustrates a plain wiring frame. This is intended for use in the wiring of large deep articles such as pails, the die being built into a slide to move on the frame shown, and hanging below the line of the bed. This arrangement makes possible the use of a standard press for wiring deep articles instead of a single-purpose press with special high die space and very long strokes.

Fig. 27 shows a horn frame fitted with a straight horn. The press as shown is adapted for setting down the side seams on pieced tinware, cans, canisters, etc.

Fig. 28 is a horn frame with sunken bolster and slide plate combined; as shown it is fitted with a tapered horn. This outfit combines those shown in Figs. 26 and 27 in convenient form so a change of tools from horning to wiring may be quickly made.

PRESS CAPACITY

In stating particulars of various machines, manufacturers will say, "Pressure exerted at bottom of stroke 350 tons," or "Pressure will exert 350 tons," and the machine will be described as a 350-ton press.

The capacity of a press to do work—its work capacity—is expressed in inch-tons and is the product of the maximum pressure it is capable of exerting and the effective distance over which it can bring the pressure to bear. In light ungeared presses this distance is $\frac{1}{16}$ to $\frac{1}{8}$ in., and from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. when geared. A 50-ton press capable of exerting this pressure through $\frac{1}{16}$ inch can effect $50 \times \frac{1}{16} = 3\frac{1}{4}$ inch-tons of work. Within the limits imposed by the working pressure of the press, distance and pressure can be varied to meet the requirements of a particular operation. The 50-ton press taken as an example can give $12\frac{1}{2}$ tons through a quarter of an inch. But it cannot do a coining operation and exert 200 tons pressure over $\frac{1}{64}$ inch. Crankshaft, frame, or belt would break under the strain.

In Table I the capacities of various crankshaft diameters are given. The figures are approximately correct and are derived from the formula—

$$\text{Maximum pressure} = KD^2$$

when D is the crankshaft diameter and K a constant for the type of press—3·5 for open-fronted, 4·0 for double-sided, 4·5 for double-sided double-crank, and 2·0 for the end-wheel type, these constants applying when the stroke of the crankshaft does not exceed its diameter.

TABLE I.—CAPACITY OF CRANKSHAFTS AT THE BOTTOM OF THE STROKE

Crank-shaft Dia. In.	*Tons*		*Crank-shaft Dia. In.*	*Tons*	
	Single-crank Press	*Double-crank Press*		*Single-crank Press*	*Double-crank Press*
$1\frac{3}{8}$	6	—	$6\frac{1}{2}$	150	150
$1\frac{1}{2}$	7·5	—	7	180	200
$1\frac{5}{8}$	9	—	$7\frac{1}{2}$	215	243
$1\frac{3}{4}$	10·5	—	8	255	290
$1\frac{7}{8}$	12	—	9	345	400
2	14	—	10	440	525
$2\frac{1}{8}$	16	—	11	545	700
$2\frac{1}{4}$	18	—	12	665	900
$2\frac{1}{2}$	22	22	13	790	1,150
$2\frac{3}{4}$	26·5	26·5	14	920	1,400
3	31·5	31·5	15	1,060	1,700
$3\frac{1}{4}$	37	37	16	—	2,000
$3\frac{1}{2}$	43	43	$16\frac{1}{2}$	1,300	—
4	56	56	17	—	2,300
$4\frac{1}{2}$	71	71	18	1,560	2,700
5	88	88	20	1,950	3,400
$5\frac{1}{2}$	106	106	22	2,380	4,200
6	126	126	24	2,860	—

The crankshaft diameters are the frame-bearing sizes of typical standard presses. The capacities given are conservative pressures which the presses will stand at the bottom of the stroke, but the tonnage figures do not apply to end-wheel type of presses with overhanging crankpin.

NOTES ON SELECTING THE PROPER PRESS

Selection of the proper press for a given kind of work may depend on :

(1) The size and type of die required.

(2) The amount of stroke necessary.

(3) The pressure required for doing the work.

(4) The distance above the bottom of the stroke where this pressure first occurs.

(5) Any additional pressure required due to attachments such as are used for drawing work.

(6) The method of feeding, the direction of feed, and the size of sheet, blank, or article, may also determine the size of press.

When the pressure occurs at or near the bottom of the stroke with a comparatively short stroke, the tonnage mentioned in the table is safe for a given size of crankshaft, as most presses have been designed to withstand the listed pressure at the bottom of the stroke. At this point the crankshaft is under a bending load similar to a beam.

When the pressure occurs at quite a distance above the bottom of the stroke, or when the length of stroke required is comparatively long, as in toggle drawing presses, thereby increasing the effective crank arm, the load on the crankpin produces a torsional load on the crankshaft. This load on the crankpin is limited by the gearing and the amount of torsion that the crankshaft will safely stand.

On some single-crank presses with very long stroke, on double-crank presses of great width or with long stroke, and on all large single- and double-crank presses, "twin gearing," or a gear on each end of the crankshaft, is employed. This arrangement increases the gearing strength and torsional capacity of the crankshaft, and in the case of wide double-crank presses, reduces the torsional deflection of the crankshaft. Under these conditions the load at the bottom of the stroke would still be limited by the figures given in the table. In all cases where twin gearing is used, the press would be operated by a friction clutch.

When there is any doubt as to whether or not a certain press will do a given piece of work, it is advisable to confer with the makers direct, giving them all the information and details obtainable.

Table II.—Average Ultimate Strength of Materials
Pounds per Square Inch

Material	*Shear*	*Compression*	*Tension*
luminium, cast	12,000	12,000	15,000
,, soft sheet	15,000	—	15,000
,, half hard sheet	19,000	60,000	19,000
,, hard sheet	25,000	—	28,000
sbestos millboard	3,800	—	—
rass, cast	36,000	30,000	30,000
,, drawing, soft sheet	30,000	—	47,000
,, half hard sheet	35,000	—	60,000
,, hard sheet	40,000	—	85,000
ronze, gunmetal	30,000	20,000	40,000
,, phosphor, soft sheet	40,000	—	45,000
,, manganese	—	120,000	70,000
opper, cast	25,000	40,000	24,000
,, rolled	28,000	60,000	37,000
upronickel	40,000	—	66,000
uralumin, soft sheet	30,000	50,000	35,000
,, treated	35,000	60,000	55,000
,, treated and cold rolled	40,000	75,000	75,000
ibre, hard	24,000	—	—
erman silver, half hard	32,000	—	—
on, cast	25,000	90,000	22,000
,, ,, 2% nickel	50,000	150,000	50,000
,, wrought	40,000	46,000	50,000
on wire, annealed	—	—	45,000
,, ,, unannealed	—	—	80,000
ead	4,000	—	3,000
eather, chrome	7,000	—	10,000
,, oak	7,000	—	4,000
onel metal, cast	60,000	—	75,000
,, ,, rolled	65,000	90,000	95,000
icro copper	30,000	—	37,000
aper, hollow die	3,000	—	—
,, flat punch	8,500	—	—
,, Bristol board, flat punch	4,800	—	—
,, strawboard, flat punch	3,500	—	—
lver	30,000	—	38,000
eel, casting	60,000	65,000	70,000
,, boiler plate	60,000	70,000	70,000
,, drill rod, not tempered	80,000	—	130,000
,, silicon	65,000	—	65,000
eel, stainless	70,000	—	95,000
,, ·10 carbon (soft)	45,000	60,000	60,000
,, ·25 carbon (mild)	55,000	65,000	70,000
,, ·50 carbon	70,000	—	95,000
,, ·75 carbon	80,000	—	115,000
,, 1·00 carbon	85,000	—	130,000
,, 1·20 carbon tool steel annealed	95,000	—	150,000
,, 1·20 carbon tool steel tempered	190,000	—	250,000
n, cast	3,200	6,000	3,500
,, sheet	5,000	6,500	5,000
nc, sand cast	14,000	20,000	9,000
,, die cast	16,000	—	15,000
,, rolled	18,000	—	24,000

USEFUL FORMULÆ FOR CALCULATING PRESSURES

for various types of press work

It is always a temptation to be over-optimistic as regards the capacity of a press which has been performing perfectly because it has been working within its capacity. A heavier operation is tried, and this again is successfully accomplished, possibly because it is still well within the compass of the press and sometimes because the generous margin of safety which the manufacturer has allowed for in his design is taking care of the extra strain involved, although the operation is really beyond the stipulated capacity. The following formulæ are useful in determining the pressures involved in the commoner operations met with in the press shop. By making the simple calculation involved it is possible to determine whether or not the work in question is possible, and thus to avoid putting undue strain on expensive machinery, which will certainly shorten its life, if not bring production to a stop owing to breakdown.

Pressure Required for Blanking Soft Mild Steel, Copper, Brass and Aluminium

Take the—

Length of Cut in inches × Thickness of Material in inches × Shear Factor in tons per sq. inch.

The shearing factors for the metals commonly used for press operations are :

(1) Soft Mild Steel—20 tons per sq. inch.

(2) Soft Copper, ,, Brass, Aluminium —12 tons per sq. inch.

(3) For harder qualities of steel take a figure equal to 75 per cent. of the tensile strength of the material.

These figures are the *Theoretical Shearing Pressure* and are correct when all the equipment is in perfect order. To counteract such possibilities as the defective grinding of tools, variations in the thickness or hardness of the metal and inaccuracies in tool setting, a further margin of safety, at the discretion of the user, is advisable to prevent fatigue in the machine. This more conservative figure may be called the *Practical Shearing Pressure.*

Example : To find the pressure required to cut out a rectangular blank, 6 in. × 4 in. × $\frac{1}{4}$ in. thick, as in sketch ; length of cut = 6 in. plus 4 in. plus 6 in. plus 4 in. = 20 in. × $\frac{1}{4}$ in. = 5 square inches of metal.

For soft mild steel this will mean a pressure of 5 × 20 tons = 100 tons. For the non-ferrous metals the pressure would be 5 × 12 tons = 60 tons. These pressures are correct for flat tools, but by putting " shear " on the punch or die, it is possible to reduce the load by approximately 20 per cent.

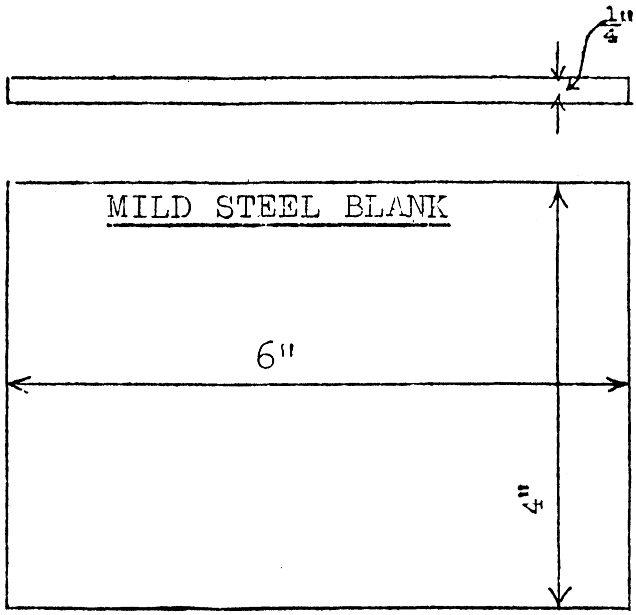


Fig. 29.—Calculation of Pressure for Blanking

It should be noted that " shear " is put on the die, and the punch left flat if the blank which is being cut is required to be flat. If, on the other hand, it is desired to keep the *sheets flat*, the " shear " must be put on the punch. No shear should be put on tools for cutting thin material—up to $\frac{1}{32}$ in. in thickness.

The following is an additional list of the shearing factors for obtaining blanking or shearing pressures for various materials often used in single-action press operations.

Constants for Obtaining Blanking or Shearing Pressures for Various Materials (Constants to be 20 per cent. Less for Punches having Shear)

Aluminium Castings	6·0
Aluminium Sheets	10·0
Brass Castings	18·0
Brass Sheets (half-hard)	13·0
Bristol Board (using dinking die)	1·5
Bristol Board (using flat-end punch)	2·5
Copper Castings	15·0
Copper (Rolled)	12·0
Fibre (Hard)	11·0
German Silver (half-hard sheets)	16·0
Iron (Cast)	20·0
Iron (Wrought)	20·0
Lead	1·5

Leather (Chrome)	3·5
Leather (oak)	3·5
Paper (using dinking die)	1·5
Paper (using flat-end punch)	3·2
Rawhide	6·5
Steel Boiler Plate and Angle Iron . .	20·0
Steel (cold-drawn rod)	29·0
Steel (Drill Rod—not tempered) . .	40·0
Mild Steel (·45 carbon)	30·0
Steel (Mild C.R. Sheets)	25·0
Steel (Soft Mild)	20·0
Steel (Nickel 3 to 5 per cent.) . . .	40·0
Steel (Spring 1·00)	42·0
Steel (Spring 1·20 carbon not tempered) .	45·0
Steel (Sheet tin-coated)	25·0
Steel (Tool red-hot)	10 to 15
Strawboard (using dinking die) . . .	1·0
Strawboard (using flat-end punch) . .	1·95
Zinc (rolled)	9·0

Pressure Required for Bending Operations

This radius must not be less than twice the thickness of the metal.

Take the—

Length of Bend in inches × Thickness of Material in inches × Bending Factor in tons per square inch

In this type of operation it is assumed that the material is merely bent, and not pinched or coined in any way.

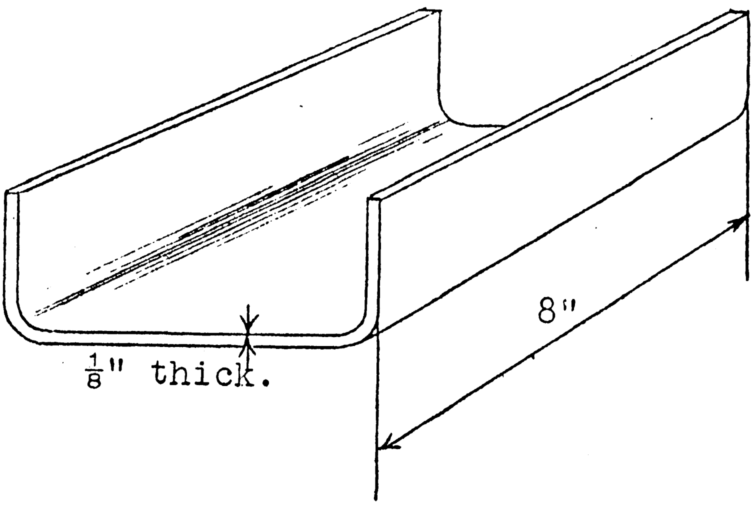


Fig. 30.—Calculation of bending pressure

The Bending Factors for the various materials are :—

Mild Steel	10 tons per sq. inch approx.
Hard Steels	20 tons per sq. inch approx.
Aluminium	6 tons per sq. inch approx.
Soft Brass, Soft Copper	6 tons per sq. inch approx.
Hard Brass, Hard Copper	8 tons per sq. inch approx.

In this particular example, the length of the bends = 8 in. + 8 in. = 16 in. × $\frac{1}{8}$ in. = 2 square inches of metal bent = 20 tons pressure required to do the work in mild steel.

Pressure Required for Drawing Operations

Double-action Presses. In such operations the total pressure required is approximately equal to the amount for cutting out the blank from which the shape is formed. Make sure that correct clearance between the punch and die is always provided. The total pressure should be divided between the pressure plate and punch in the proportion of 25 per cent. to 30 per cent. to the former, and 70–75 per cent. to the latter.

Formula for Calculating Size of Blank for Cups without Top Flange

$$D = \sqrt{d^2 + 4\,dh}$$

This is only correct when no changes take place in the area and thickness of the metal while the blank is being transformed into a shell.

Where cups are formed in combination tools in single-action presses, the total capacity of the machine must be equal to :

1. Pressure required to cut out blank.
2. Pressure required to form into cup and emboss.
3. Pressure required to compress spring or rubber buffer attachment, or air cushions, as the case may be.

For Embossing Letters, Figures, or Designs

This type of operation requires the same pressure which would be necessary for cutting out a blank of the same size. The operation must really be considered as a drawing operation (as in " C "), and it is assumed that the material is *not coined or thinned in any way.* When thinning or coining takes place, due either to faulty tool setting or thick material, the pressure curve goes up enormously, even to as much as 100 tons per square inch over the area of metal pinched or coined.

Pressure for Coining Operations : Thinning the Material in Squeezing Processes Cold

For this class of work a pressure of approximately 100 tons per square

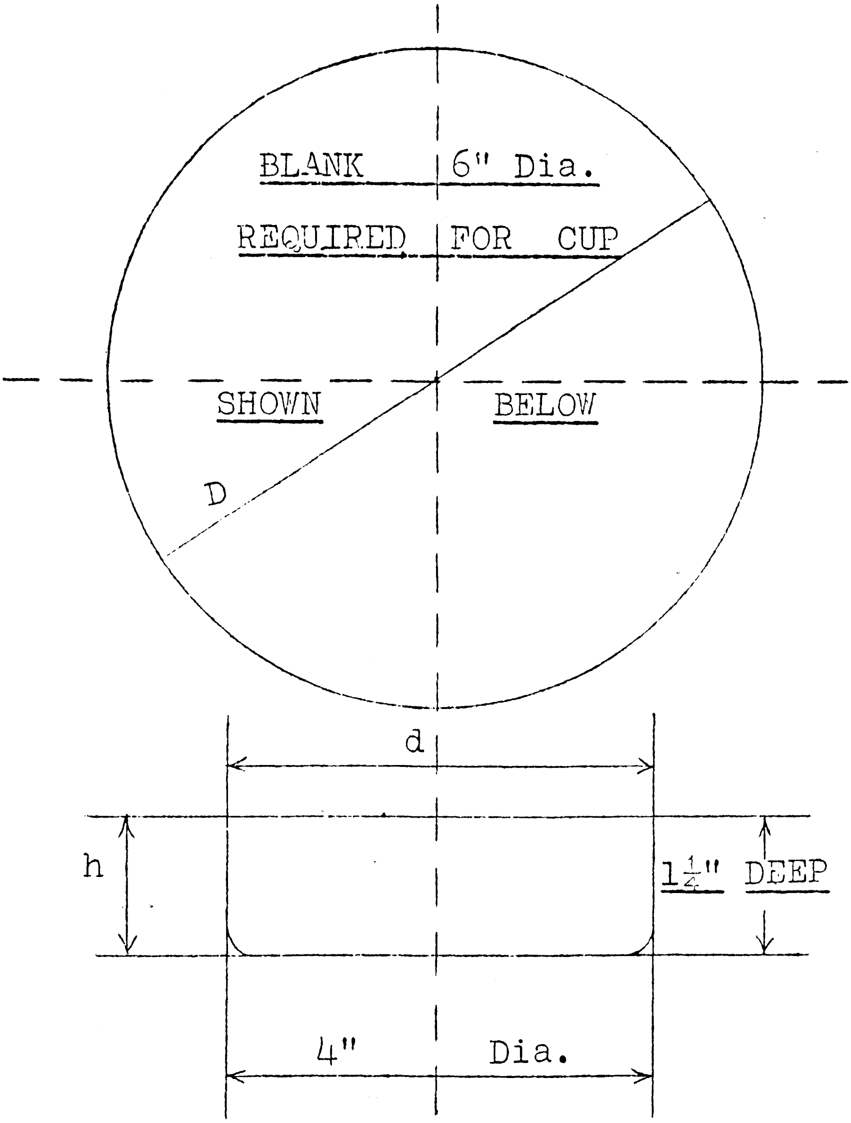


Fig. 31.—CALCULATION FOR CUPPING OPERATION

inch for mild steel and 60 to 100 tons per square inch for non-ferrous metals is required.

Pressure Required for Hot Brass Pressing Operations

In forging yellow metal (60 per cent. copper plus 40 per cent. spelter) at a temperature of 700° C. to 750° C., according to the size of the billet, a pressure of 20 tons per square inch is required over the area of the article plus the area of flash which is formed during the pressing operation.

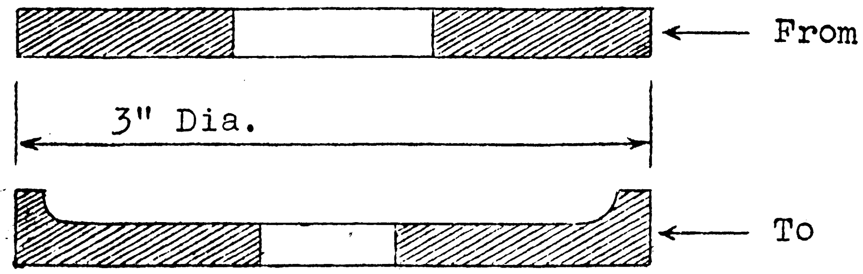


Fig. 32.—CALCULATION FOR FLANGING

It is essential in these hot pressing operations to do the work at the correct temperature.

Approximate Clearance between Punch and Die on Diameter

(*a*) Clearance for brass and soft steel: take thickness of stock and divide by 10.

(*b*) Clearance for hard rolled steel = thickness of stock divided by 8.

Table of Penetration

The following table shows to what extent punches have to penetrate into mild steel to effect complete severance of the material.

Thickness in inches	1 in.	$\frac{1}{2}$ in.	$\frac{1}{4}$ in.	$\frac{1}{8}$ in.	$\frac{1}{16}$ in.
Percentage of thickness	·25 per cent.	·37 per cent.	·50 per cent.	·62 per cent.	·75 per cent.
Equivalent in inches	·0025 in.	·00185 in.	·00125 in.	·0008 in.	·0005 in.

From this table it will be seen that the percentage of penetration of the punch into the thinner materials before the metal is severed is greater than for the thicker gauges.

Centre of Gravity of Irregular Blanks

In the case of irregular-shaped blanks it is essential, to ensure that the load on the press is evenly distributed, to find the centre of gravity of the cut. This can be done readily by bending a piece of fine wire to the shape of the cutting edges and balancing this formation of wire on a straight-edge over two centre lines drawn at right angles to each other.

Hydraulic and Baling Presses

Hydraulic presses are used in many branches of industry in plants throughout the world. Hydraulic presses are used in forging plants where high pressure, exact movement of the platen, and uniform operating cycles are required. They are used extensively in automobile body-stamping plants where accuracy and dependability are important. Similar presses are used in the aircraft industries in conjunction with modern manufacturing methods for producing fuselage parts, wing sections, landing gears, ailerons, cabin side sheets, etc.

Smaller hydraulic presses are used in the manufacture of a large variety of ferrous and non-ferrous deep-drawing work. They are used in the manufacture of hardware, domestic and commercial cooking utensils, ornaments, medals, coins, stove and refrigerator parts, and general forming of all kinds. A modern press designed for precision die work is illustrated on this page.

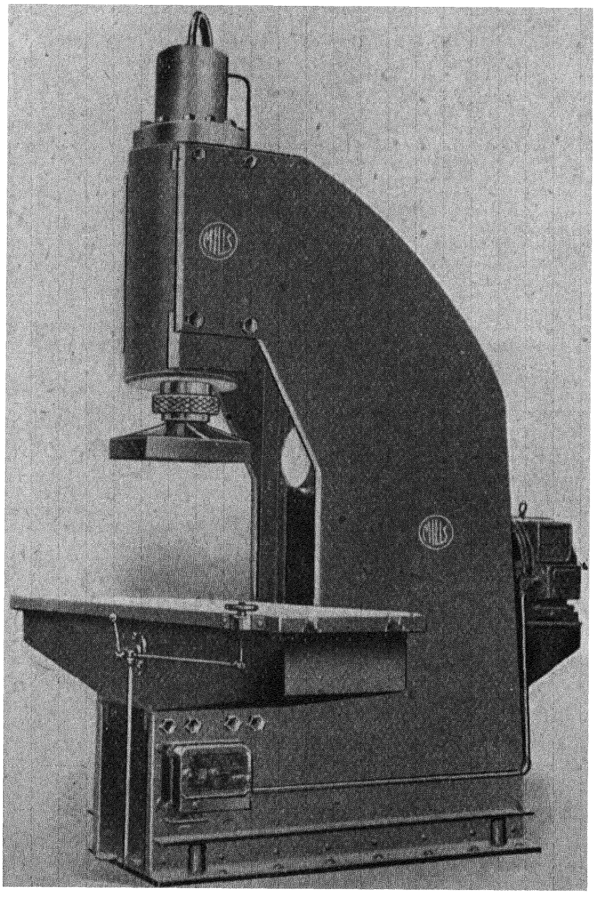


Fig. 33.—PRESS FOR PRECISION DIE WORK
(*John Mills & Co.* (*Llanidloes*) *Ltd.*)

This press is fitted with special fine adjustments for regulating pressure stroke. It deals with thin wall pipes of copper, aluminium or other non-ferrous metal liable to crush and distort. The press employs wooden dies and will deal with pipes up to $4\frac{1}{2}$ in. in diameter. There is vernier adjustment on the control.

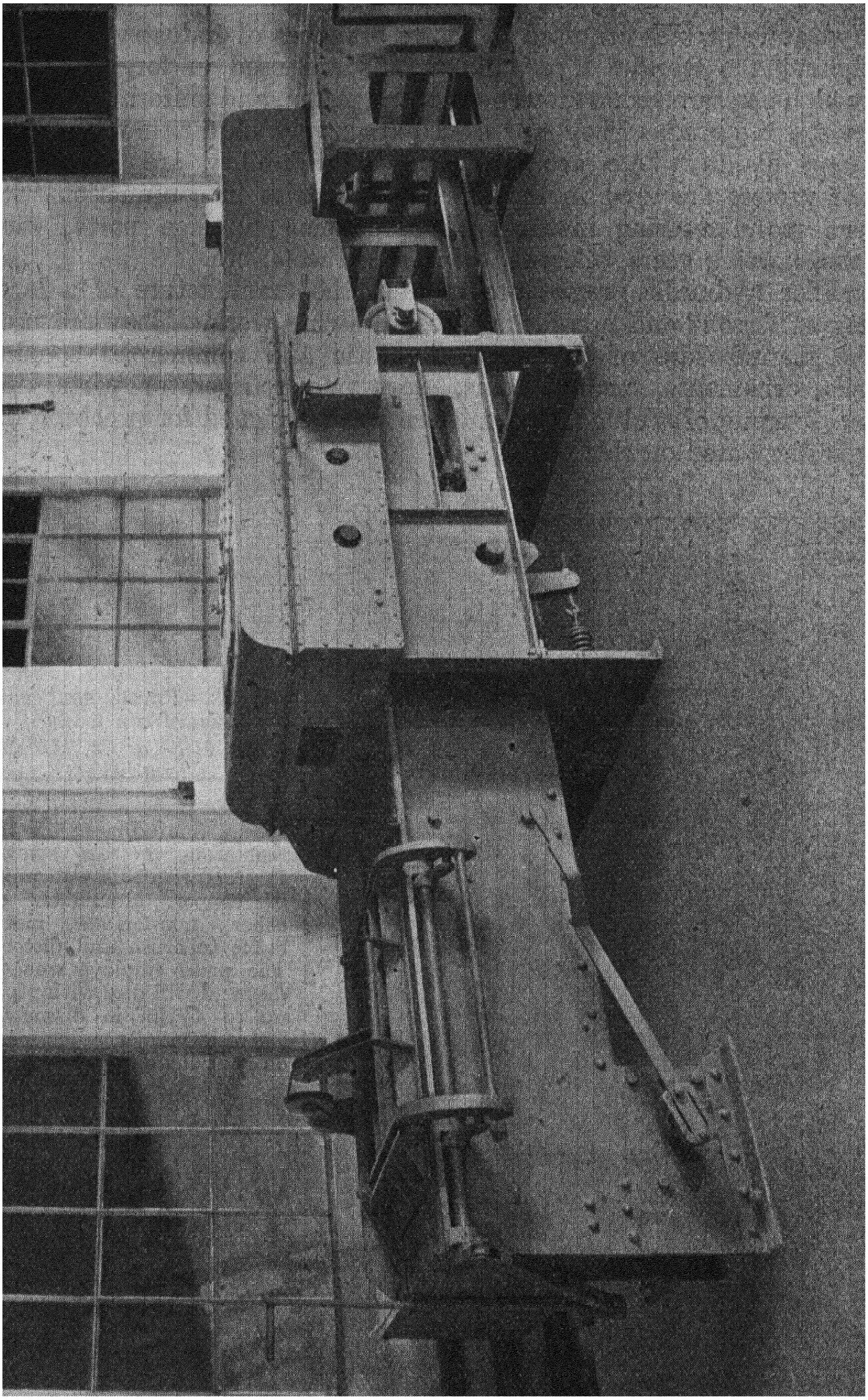


Fig. 34.—Mechanical baling press for tins, etc. (*Heenan & Froude, Ltd.*)

High Production

In the metal-stamping industry the use of the hydraulic press is of comparatively recent date. Prior to this time few attempts had been made at such applications due to the very limited production capacity of the single-pressure ram-type hydraulic press. However, certain characteristics of the hydraulic press, such as uniform pressure available at any point of the stroke and variable length of stroke, have always been recognised as being most desirable. The development of dual- and triple-pressure hydraulic circuits and the application of the rotary-type hydraulic pump have made the hydraulic press a modern high-speed production machine.

Precision

Modern dies are the precision production tools of the manufacturing industries. They are made from the best engineering materials by skilled toolmakers and represent a major portion of tooling costs. The accuracy and life of these dies depend upon the press in which they are used. Precise, parallel movement of the slide in relation to the bed is of primary importance and is featured in modern hydraulic-press design.

The addition of a simple compact hydraulic pumping system satisfies industry's demand for a hydraulic production unit which will give dependable and accurate results.

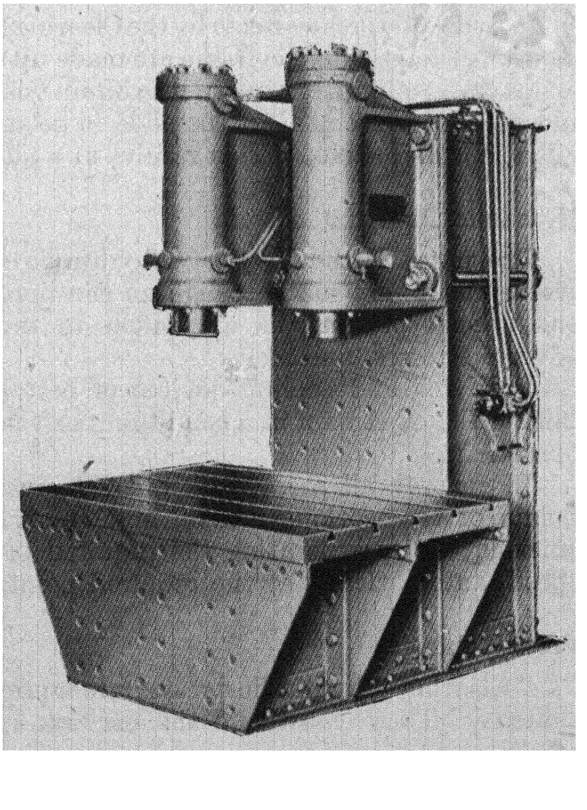


Fig. 35.—A 100-TON DOUBLE-RAM HYDRAULIC PRESS

(*Hugh Smith & Co.*)

The press is of fabricated construction with 50 tons on each ram. The rams can be worked independently for repetition bending work, one bending and the other vicing, or they can be coupled together by a crosshead and used as a 100-ton press.

Flexible Control

Movement of the platen, and the pressure exerted by hydraulic presses, are under control of the operator at all times. The pressure is built up gradually, giving the metal opportunity to flow as directed by the die contours. The force exerted is in direct proportion to the work resistance encountered, with a gradual pressure being built up to a predetermined maximum for the final set. The maximum amount of pressure exerted is fixed by adjustment of the pressure-controlled hydraulic valve. Semi-automatic or fully-automatic operating cycles are obtainable. The extreme flexibility of hydraulic control lends itself to the relatively small movements of the platen required in die setting. Inching control is provided for the up and down movement of the platen and the press can readily be adapted to meet the requirements of a variety of jobs.

Distinctive Features

Machinery in general is frequently likened to living organisms. Hydraulic presses approach this comparison closer than other types of machines by incorporating four distinct systems which may be compared to similar systems in living beings. The frame structure of the press corresponds to the muscular system, the pumping unit to the circulatory system, the electrical control to the nervous system, and the oil-conditioning devices constitute the glands.

In hydraulic presses made by the Clearing Machine Corporation, Chicago, the parts comprising the frame are made up of welded steel plate arranged to maintain alignment with maximum load conditions, to give precise and parallel movement of the slide in relation to the bed and to absorb vibrations and shock. This results in a simpler hydraulic system.

Hydraulic Pumping System

The pump is the heart of a hydraulic press. In modern systems all arrangements are made to lighten the burdens imposed upon the pump and special precautions are taken to protect it against overloading, adverse stresses, and shock.

Purifying and cooling devices of best quality are applied for maintaining the oil stream in a condition most favourable to continuous pump operation.

In general, all press work offers increasing resistance at progressive points of the working stroke, and one way of securing high practical efficiency is by generating the required pressures in steps of maximum speed, automatically at the required points of the stroke.

Press Controls

" Clearing " hydraulic presses are equipped with automatic electrical controls. These constitute the nervous system of the press. As such

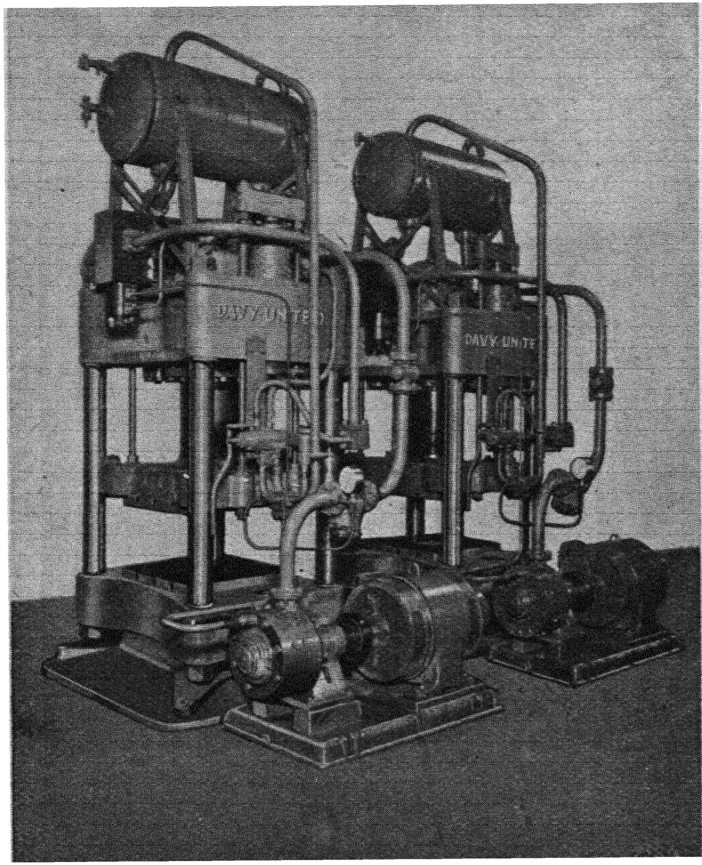


Fig. 36.—Two 150-ton self-contained hydraulic piercing press (*Davy & United Eng. Co. Ltd.*)

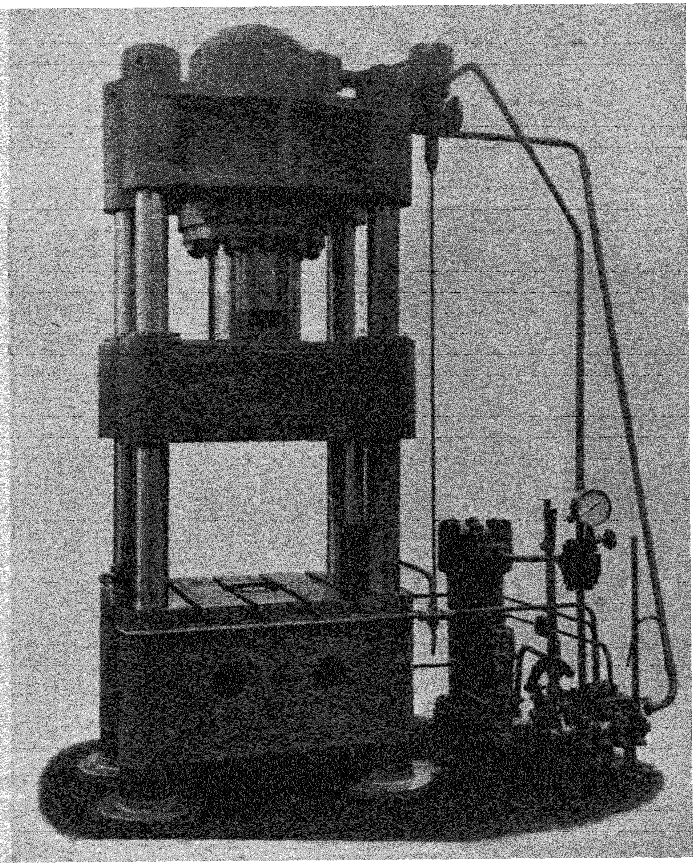


Fig. 37.—A 250-ton bakelite moulding press (*Leeds Eng. & Hydraulic Co. Ltd.*)

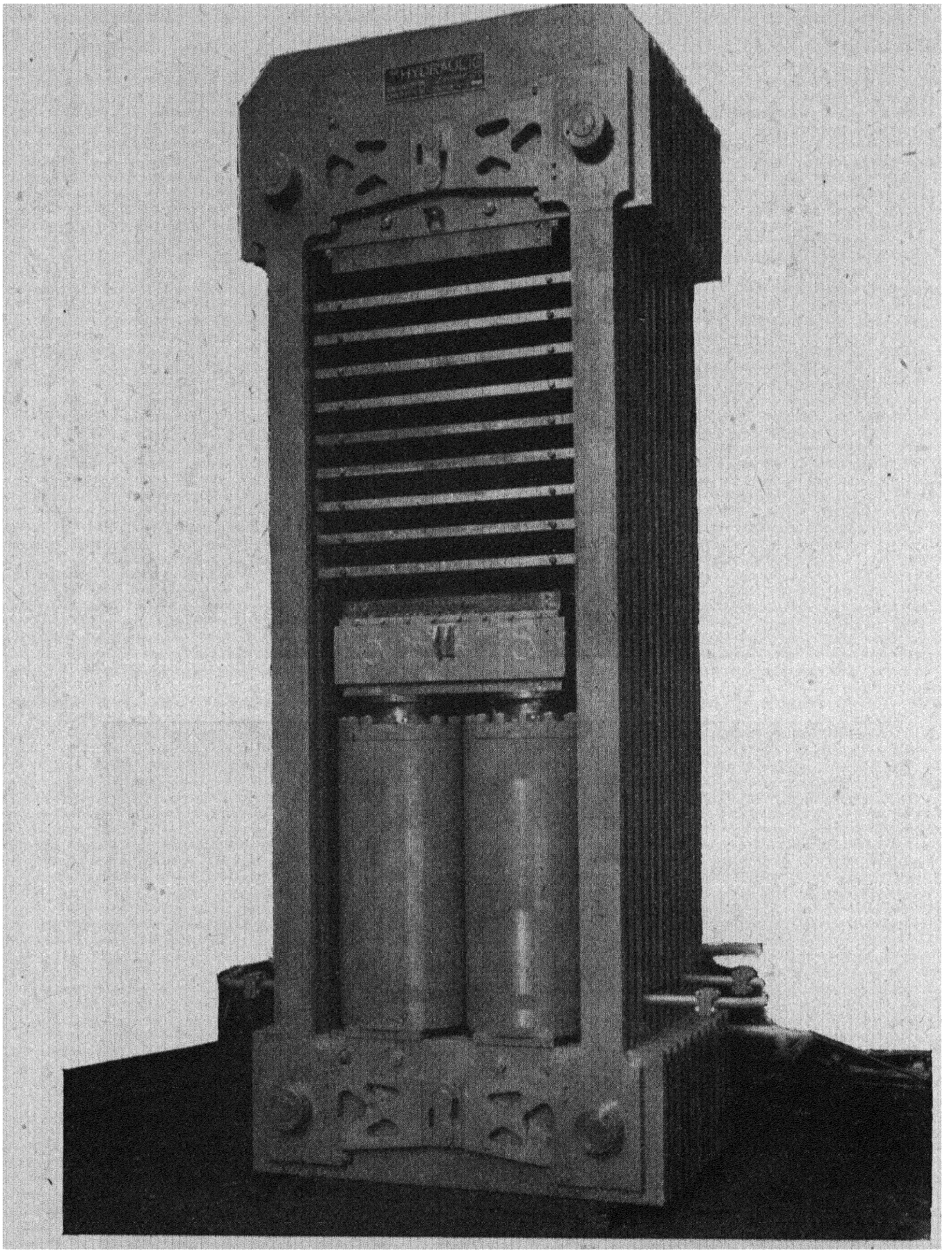


Fig. 38.—2,600-TON HOT-PLATE PRESS, TOTAL WEIGHT 100 TONS

(*The Hydraulic Engineering Co. Ltd.*)

This press, of patent laminated construction, permits expansion of the press head relative to the base without causing any distortion.

they are arranged to give instantaneous and sensitive response to the impulses given by the operator, and automatically transmit other impulses to give the full cycle either between fixed stroke limits or under pressure regulation. Controls are arranged for complete automatic or semi-automatic cycles and for sensitive inching during die setting. All controls consist of high-grade electrical apparatus and are installed in easily accessible positions on the press frame.

A 4,000-ton Hydraulic Press

Although power presses are usually associated with hardened steel dies, and are normally used for quantity repetition production, there are some classes of work which involve a relatively limited output, at a more leisurely pace. This is particularly the case with modern aircraft production, in which the airframe is frequently of sheet-metal construction. Obviously, too, the actual number of operations at this stage of the job is considerably less than is involved in the manufacture of many of the smaller component parts.

It follows, therefore, that for limited runs, it is better whenever possible to limit the time and expense which would be incurred if the usual steel dies were used, and, indeed, it would often happen that these tools would be discarded while still in nearly new condition. These related facts have induced many manufacturers to adopt thick rubber pads in place of the usual bottom forming die.

One of the largest presses in this country to operate in this manner is the 4,000-ton hydraulic press installed at the Bristol Aeroplane Company's works. It was designed and built by Messrs. Fielding & Platt, Ltd., of Gloucester. This press weighs about 300 tons and is bedded into a deep concrete foundation. The ram works on vertical columns, and the design permits access from all sides, for loading or unloading the dies. These comprise a wooden or zinc template or male die, shaped to the internal form of the part, and this is placed on the press table. Over this is laid the sheet-metal blank. On the moving ram is a thick rubber pad, which descends and forces the sheet blank to shape over the male die. Obviously, blanking can also be done in this way, in which case a harder rubber pad is used.

Hydraulic Operation

The press is driven from a battery of four multi-plunger pumps, each of which operates at a pressure of 2 tons per square inch. Each pump is driven by a 75-h.p. motor, and the speed of the moving ram can be varied by isolating one or more of the pumps. No hydraulic accumulator is used in this installation. There are three methods of operation. The ram can be fed down very slowly by inches—" inching " is the expression used—this slow controlled motion being very useful when a new set-up of

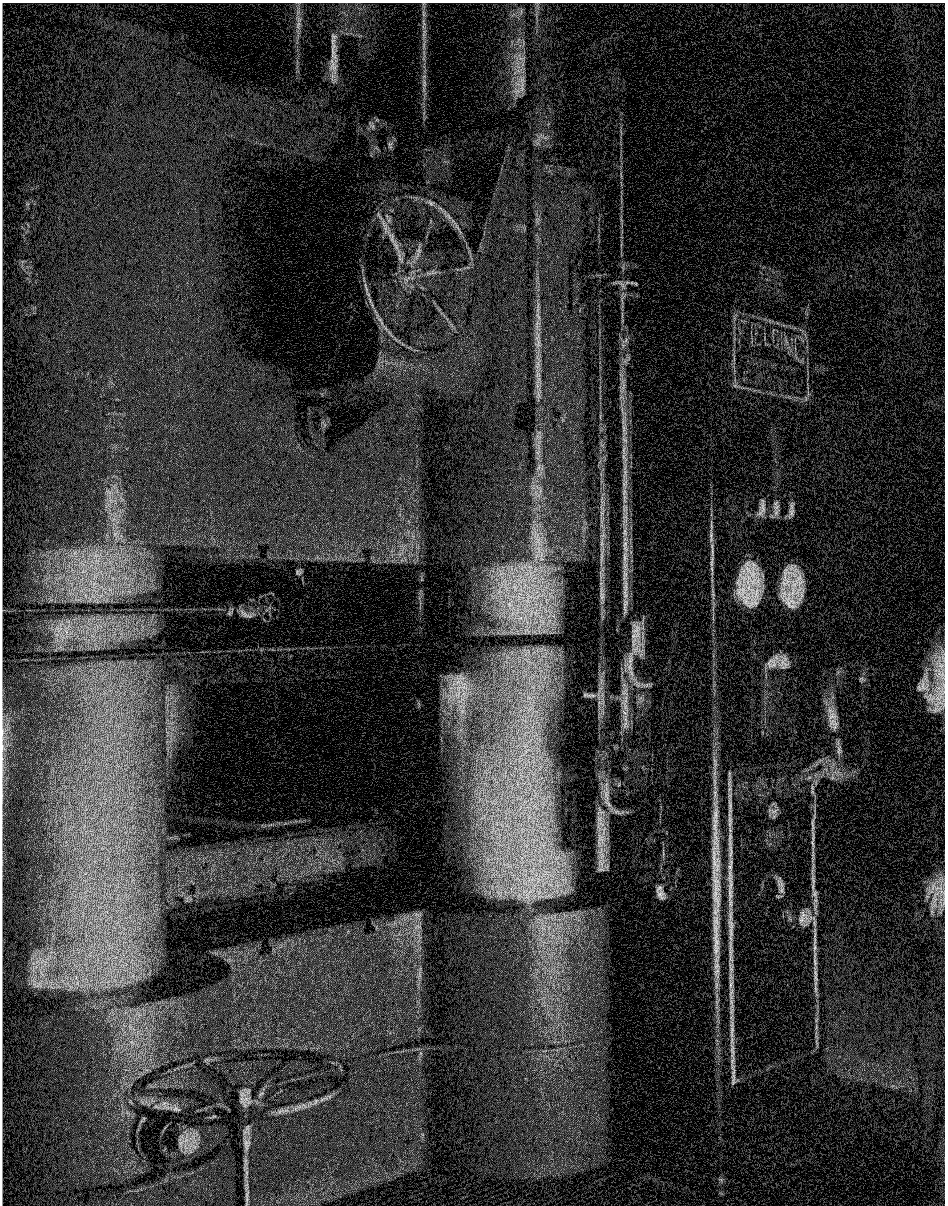


Fig. 39.—FIELDING & PLATT 4,000-TON HYDRAULIC PRESS WHICH IS ELECTRICALLY CONTROLLED BY PUSH BUTTONS FROM A PANEL AT THE SIDE

On the left in the foreground may be seen the detachable handwheel for use during the process of revulcanising the rubber pad.

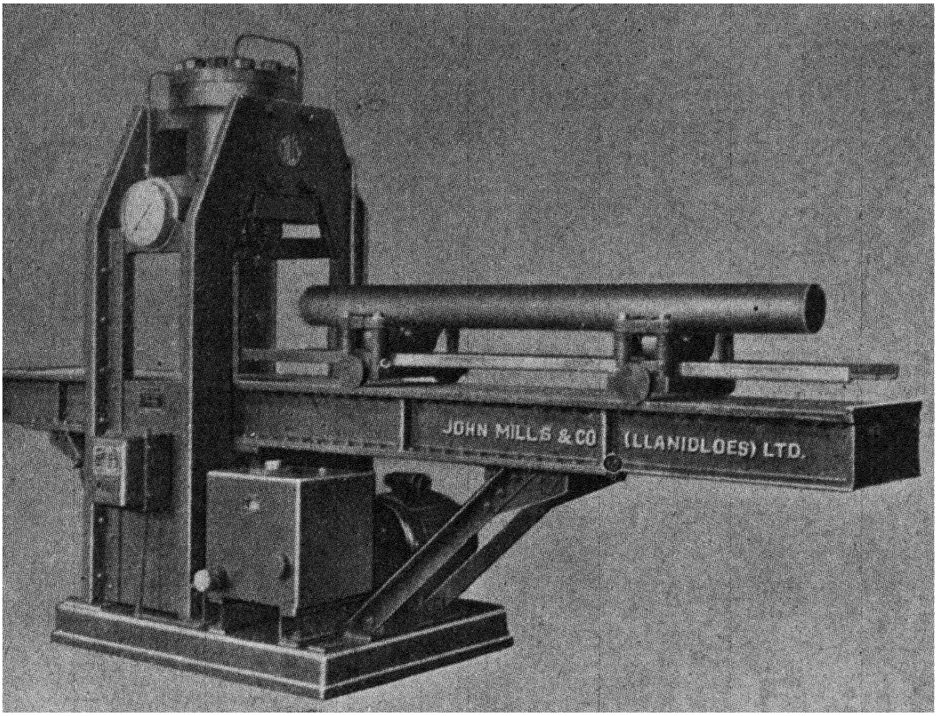


Fig. 40.—STANDARD DOUBLE-SIDED "OILAULIC" PRESS
(*John Mills & Co. (Llanidloes) Ltd.*)

This press, of 100/120 tons capacity, has a patent spring-supported travelling carriage for gun-barrel straightening and similar work.

tools is being made. The second method of operation is a complete cycle of one set of movements, when the ram makes one down and one up stroke, and then stops. Or, thirdly, this cycle can be repeated continuously and automatically.

The rubber pad measures 8 ft. by 4 ft., and it is steam heated. If the rubber should be torn or damaged, it can be patched or rebuilt on site. The damaged portion is cut away, and is replaced by uncured rubber in plastic state. The ram is then lowered to the plane table, and the steam heat turned on for about twenty hours, thus effectively vulcanising the repair.

The size of the press permits multiple dies to be used simultaneously, and, for example, such things as ribs or tank diaphragms are located by dowel pins into a plate of mild steel. It has been found that better pressing of some alloys is obtained by two low-power strokes of the press with a dwell on each, instead of using one heavy stroke. It has been found possible to deal with mild-steel sheets up to 10 s.w.g. thickness with absolute success.

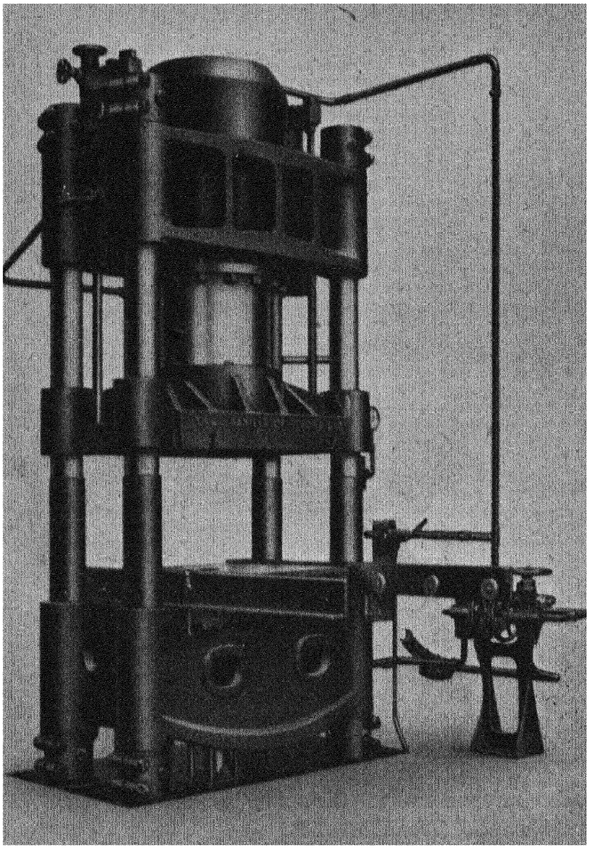


Fig. 41.—A 500-TON HYDRAULIC MOULDING PRESS

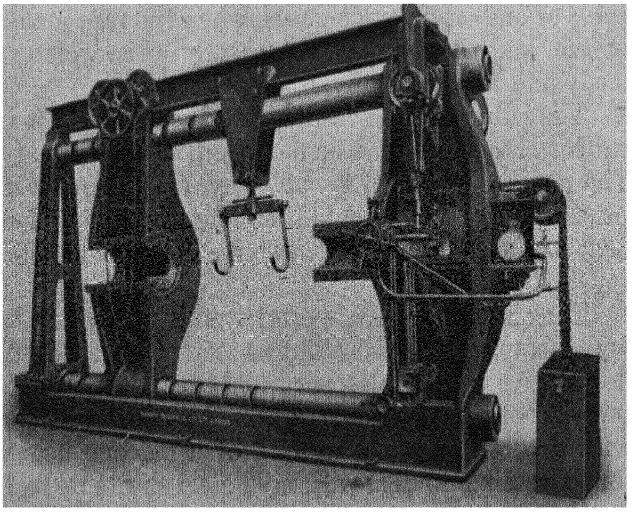
(*T. H. Daniels Ltd.*)

This press has a 26-in. ram, and a working pressure of 2,240 lb. to the square inch. A sliding worktable is shown fitted to the press.

Fig. 42.—A HORIZONTAL-TYPE PRESS

(*Henry Berry & Co. Ltd.*)

The press on the right is used for forcing wagon and locomotive wheels on and off their axles. The machine has a self-contained hydraulic pump and automatic pressure-recording gauge.



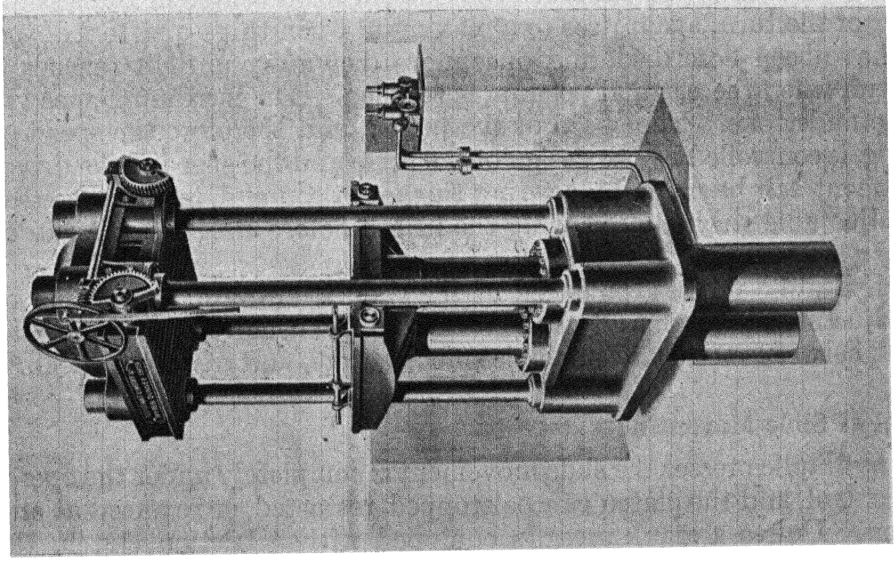


Fig. 43.—Hydraulic Packing Press with two 17-in. Rams
(*Urquhart Lindsay & Robertson Orchar, Ltd.*)

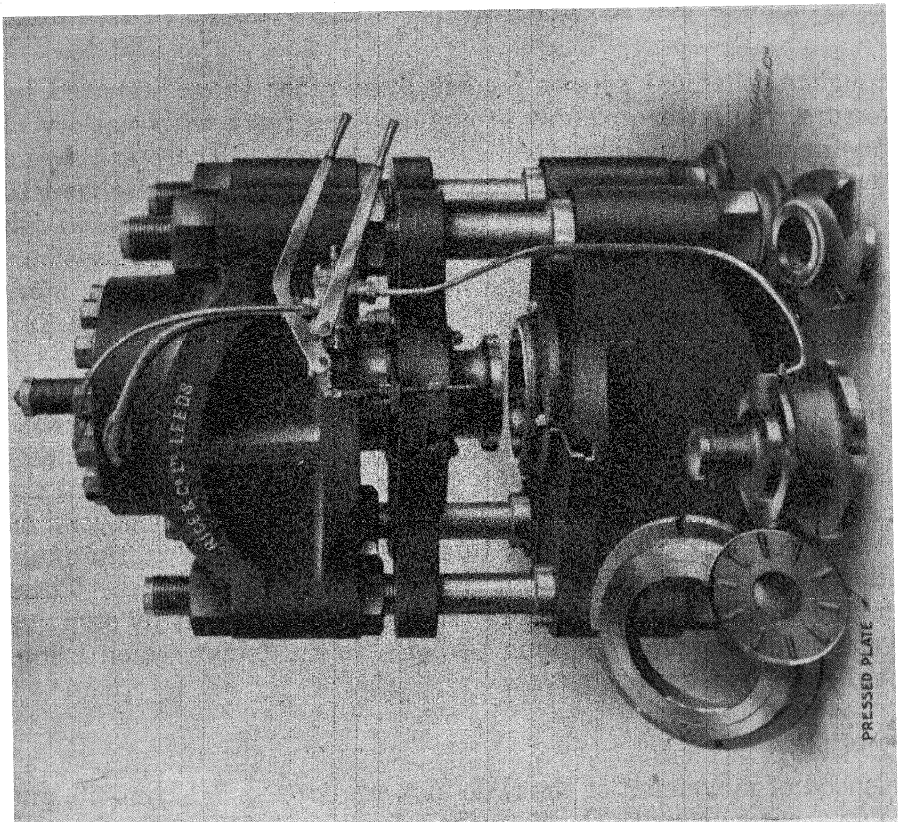


Fig. 44.—A Four-column Press
(*Rice & Co. (Leeds) Ltd.*)

Relative Advantages and Disadvantages of Crank Presses and Hydraulic Presses

Although mechanical presses greatly outnumber those actuated by fluid pressure, the latter are now in common use for a wide variety of operations in which they give excellent performance. There can be no doubt that its field of action will increase, but it is an overstatement to say that the future of the press-shop lies with the hydraulic press. Both types have well-defined advantages, and equally well-defined limitations. For certain kinds of work the mechanically operated press is more efficient, more economical, more flexible, and generally better suited, and the reverse is equally true.

The two strikingly inherent defects of the crank-actuated press are the want of uniformity of the velocity of the punch on the one hand and, arising out of this, but equally important, the speed with which it impacts on the metal which is being worked. Hydraulic presses suffer from the fundamental drawback that as the metal is being worked the loading on the pressure plate varies owing to changes in pressure in the main hydraulic system which result from the resistance encountered. These changes, uncontrollable and often harmful, can only be met by stepping up the source of pressure, common to both, to an extent which brings additional complications in its train.

Velocity of Slide

The speed of movement of the slide in a crank press is harmonic, and it varies in accordance with the sine law. Starting from top dead centre of the crank, the velocity reaches a maximum in the first quarter turn, decreases to a minimum when it is at bottom dead centre in the second quarter of the turn, again rises to a maximum when three-quarters of the circle have been described, and once more dies away until it reaches a minimum when the original position is reached. The maximum speed is at slide midstroke. The speed of the punch, and therefore the speed of drawing, is controlled by the design of the press and the speed of the drive. Adjustment can be made by altering the gear ratio and, in those presses with adjustable stroke, by varying the length before starting on a run of operations.

In hydraulic presses the speed of the slide is uniform, is capable of easy adjustment, and this adjustment can be, and usually is, made so that contact between metal and punch is smooth, easy, and free from shock.

Control of Slide Movement

In hydraulic presses the slide movement is completely under the operator's control, and the platen can be stopped, restarted, or reversed at any position. Unless a crank press is equipped with a friction clutch, the crank press must go through a complete cycle, and pass through the

bottom dead centre before being brought to rest at the height of its movement.

Strokes per Minute

Mechanical power presses have a higher output than fluid-actuated machines. The number of strokes per minute which a crank press makes is constant, depending on the speed of the shaft or of the motor, and also on the gear ratio of the driving mechanism.

In hydraulic presses of the accumulator type, where there is constant hydraulic pressure in the conduit system, the number of strokes per minute depends upon the length of the stroke, for the longer the stroke the more time is taken to fill the actuating cylinder. In those hydraulic presses with separate pumps, both the length of the stroke and the pressure which the pump generates determine the number of strokes. The rate of delivery of the oil into the cylinder is slower in proportion to the increase in pressure. Hence the number of working strokes is lower, too, for the same working length of slide.

Tool-setting Time

In the time taken for setting tools the advantages are with the hydraulic press. All that is necessary is to bring tools and slides into contact, lower the slides, fix the tools, and start up. But with a crank press, after the tools have been fixed to the slides the setting of the latter has to be determined, and this takes time, for the pitman adjustment must be precise or otherwise, at the bottom of the stroke, overloading of the press will occur. Since in the hydraulic press the die can be closed without risk whilst the stroke height is being set to the closed height of the die, this gives greater latitude in die design, and dies are interchangeable between presses which have adequate slide area and clearance. The closed height of the die on the crank press must be somewhat less than the die space of the press.

Life of Tools

Since the impact of die on metal is smooth and shock-free in the case of the hydraulic press, the life of tools is longer than in the case of crank press, unless they are built on heavier and more robust lines in order to stand up to the hammer-like action. It also follows that harder and more brittle alloys can be used with hydraulic presses.

Automatic Feeds

For the ready attachment of side feeds, etc., the construction of the crank press is extremely suitable. All these attachments are mechanically worked from either the gearing or the mainshaft of the press. The ap-

plication of the various types of feeds is restricted in the fluid-actuated presses, since the feed attachments must be actuated by the slide.

Production of Large Pressings

Large hydraulic presses have come largely into use in the motor-car industry for the pressing of bodies, etc., because they have advantages for the production of large pressings of this type. They are cheaper to run. But more important, the blankholder and the drawing slide can be coupled together so that, with the combined pressure thus made available, pressings can be finished closely to size.

Inching

Simple manipulation of the lever of the valve which controls the raising and lowering of the slide in an hydraulic press makes inching an easy process. In the crank press it is far from easy, but slow and difficult, the slide being lifted by turning the flywheel or the main gear with a crowbar while the press is stationary. Where there is a friction clutch fitted, the motor is stopped or the drive slipped, and the residual kinetic energy of the flywheel used. To lift the slide the flywheel must be braked, the motor reversed, and the flywheel raced for a time in order to build up sufficient kinetic energy to lift the slide and the attached punch.

Two- and Four-point Suspension Presses

Here the advantage is with the crank press and against the fluid-actuated mechanism. For with unevenly distributed loads—and usually they are very unevenly distributed—the movement of the wide broad slide is positive and uniform, owing to the actuation from crankpins or eccentrics by solid, rigid pitmans. In multiple-plunger hydraulic presses, the unevenly distributed working loads in the die tilt the slide. The compressing fluid takes the line of least resistance, and flows into those cylinders whose plungers are meeting with the least restriction of their movement.

Maintenance

In the crank press, maintenance costs are a minimum, confined to keeping the bearings, etc., properly lubricated. But maintenance costs are of a different order with hydraulic presses. The smallest leak in an hydraulic system working at pressures varying from 1,500 to 3,500 lb. per square inch is a big matter. Losses of oil or water can become alarming and throw much more work on the pumps and motors. And in short-stroke, high-speed presses with individual pumps, temperatures have to be watched, although thermostatic control is a safeguard. But only a safeguard.

Installation and Head-room

The comparatively small amount of head-room required by a mechanical press gives wide latitude in installation, and structural alterations are seldom needed. The actual erection is, for the most part, a straightforward matter.

Hydraulic presses, with header or top-storage tanks, demand plenty of room above. They have broad, wide frames of considerable weight, whose dimensions are dependent on the main working cylinder. The cost of installation is far from negligible, for the whole hydraulic system must be built up with care and leaks completely eliminated.

Double-action Drawing

The flexibility of the hydraulic press gives it very definite advantages in double drawing, although there is always the danger inherent in uneven blankholding pressure, since the blankholder is worked by four independent plungers. But in hydraulic double-action presses the strokes, and the cycle of operations of the blankholder and of the plunger slides, can be adjusted and modified to individual requirements suited to the work to be done. This is where the flexibility of the hydraulic press shows to advantage against the fixed cycle of operations, the fixed strokes of the blankholder and the plunger slides, which limit the type of work which can be done in the press.

Chapter II

FEEDS AND FEED MECHANISMS

SHEET FEEDS

THIS is rather a general classification covering a variety of feeds which are arranged to handle whole rectangular sheets of tin plate, steel, brass, paper, or fibre. They may be used on wide presses fitted with gang dies or with shear blades. Gap-frame presses with single dies may be arranged to handle the sheet systematically back and forth across the die. These feeds require so many modifications in design that it is only possible to pick out and describe a few specific examples.

Automatic Gravity Sheet Feed

For example, there is the automatic gravity sheet feed for gang die work. It is fitted with combination dies for such work as cutting and stamping can tops and bottoms out of sheet tin plate. The press is started by depressing the foot treadle and cuts and forms six tops at each stroke, running continuously for the required number of strokes to complete a sheet, at which point it is stopped automatically. The dies are set in two rows, staggered to take fullest advantage of the stock, and are independently adjustable.

Conveyor Type

Another highly developed machine is capable of extremely high production in cutting out small printed wrappers, cutting through ten sheets at a time. The high degree of accuracy and reliability which is obviously required is provided for in the design, materials, and construction. This feed is typical of the conveyor type of sheet feeds such as are used in feeding paper, corrugated board, etc., and also in feeding plain or lithographed sheet tin to gang die presses in the manufacture of bottle caps.

Stagger Feeding

Certain single- and double-action presses, equipped with single dies, are fitted for use in the manufacture of shallow boxes, covers, can tops and bottoms, etc. The object here is economy of metal as well as rapid production. For stagger feeding, the presses are used in the inclined

position and are fitted with a table, circular cutters to separate the scrap from the sheet as it is formed, and stagger feed gauges to assist the operator in guiding the sheet. For zigzag feeding, a special automatic press of the inclinable type is provided, fitted with a feed capable of taking a larger sheet than can be conveniently handled by a man.

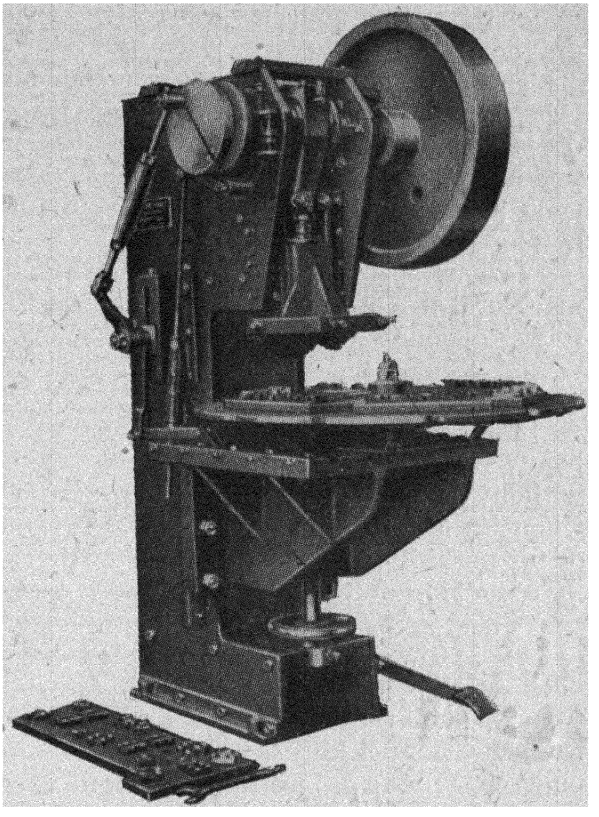


Fig. 1.—A LARGE PRESS WITH TURNTABLE FEED

Ratchet Table Feed

This consists of a horizontal feed table with an accurate ratchet-operated feeding device, on a gap-frame press. The sheet is fed into a pair of shear knives by a given amount each stroke and is cut off for hack-saw blades, etc.

GRAVITY CHUTE FEEDS

These are comparatively simple mechanisms adapted to use on presses which are either in the inclined or horizontal position. They depend upon gravity to move the work and consist as a rule only of a chute of proper dimensions and a releasing device which automatically permits only one piece to enter the die at each stroke. They may also have a device to gauge and hold the piece in the proper place during the working stroke and release it afterwards. Cam-actuated knock-outs in the bed and various ejectors can be used as required.

These feeds are varied widely to suit the particular requirements of the job on which they are to be applied. They are largely used for shaping, trimming, or lettering fruit-jar tops, or for perforating, embossing, stamping, reshaping, lettering, forming, and other operations on shells of brass, tin, zinc, copper, steel, etc., which have previously been cut and drawn, or on low cups and blanks which have sufficient thickness to prevent overlapping in the chute.

The operator simply keeps the inclined chute full of the pieces to be operated upon. These pieces drop automatically by gravity, one by one,

under the punch and, having received their operation, are discharged by gravity.

The press used may be a normal inclinable press either on standard legs or on special legs to permit increased inclining. Other types of presses, such as open-back gap-frame presses, and straight-sided presses, may be mounted on inclined legs. These and also side-wheel type adjustable bed presses are sometimes specially mounted in the horizontal position.

Various special adjustable and swinging chute feeds for automatic machines are often used on beading, flanging, trimming, and thread-rolling machines.

SINGLE-ROLL FEEDS

Single-roll feeds are applied largely to feeding strip metal which is heavy enough and stiff enough to be pushed positively across the die without buckling. They may also be used for pulling the strip through when the scrap left is so strong that there is no danger of breaking it, or for pushing the strip across when there is no scrap left to be gripped by a double-roll feed.

This type of feed is usually placed at the left side of gap-frame presses, and feeds towards the die, from left to right. On straight-side or open-back gap-frame presses they may also be placed either at the back or front, though the latter is more usual. While these are usually arranged to push the stock through, towards the die, they may also be arranged to pull the strip across the die by means of the scrap if required. In such cases the stock is started by hand until the scrap can be taken by the feed rolls.

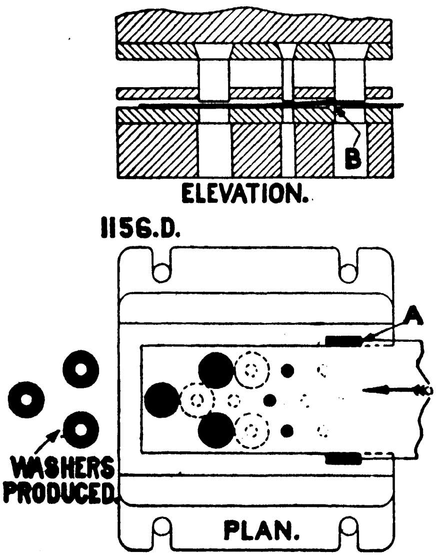


Fig. 2.—PRODUCTION OF WASHERS ON A ROLL-FEED PRESS

DOUBLE-ROLL FEEDS

Double-roll feeds, that is, feeds with a pair of rolls each side of the die, should maintain a steady tension on both the strip and the scrap so that there is no possibility of buckling. This keeps the strip under control both at the beginning and ending of the feeding. They are usually built with straight roller-grip drive for short feeds and a combined roller-grip and rack drive for long feeds. These can be adjusted to the smallest fraction of an inch and will feed paper or the thinnest ribbon metal or heavy strip metal with accuracy.

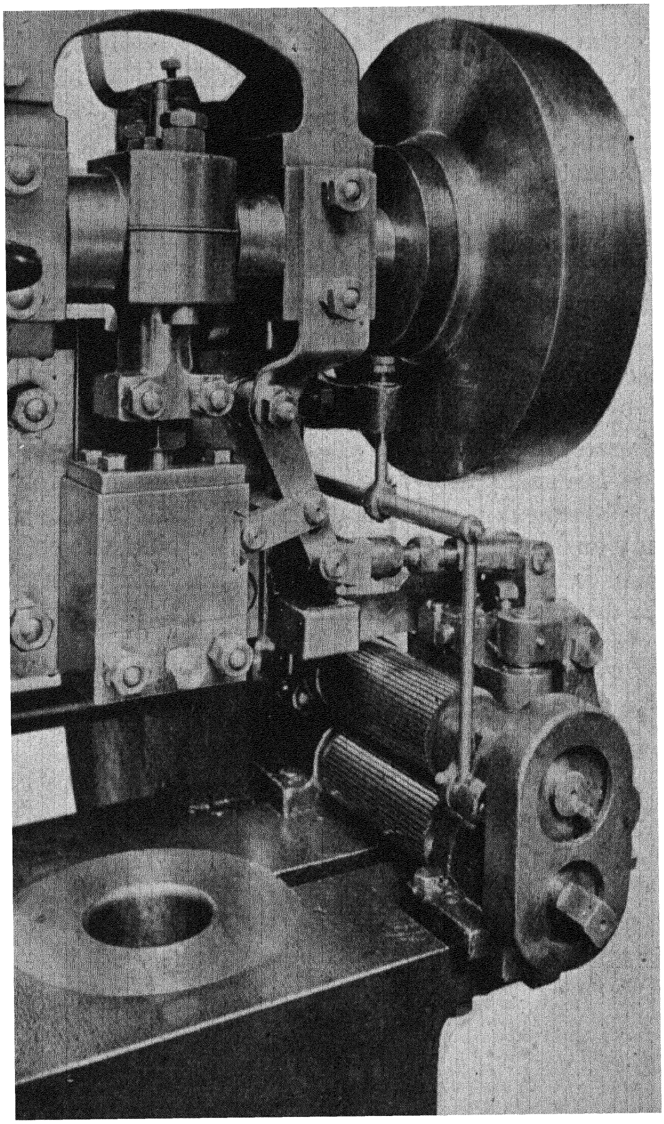


Fig. 3.—DETAILS OF A SINGLE-ROLL FEED
(*Messrs. Taylor & Challen, Ltd.*)

When ordering roll feeds, it is always advisable, and in many cases necessary, to equip presses having roll feeds with intermittent brake and locking pawl. In fact, when an intermittent brake is used it is necessary to have the locking pawl. Rack feeds cannot be used on presses having end-wheel type drive. When roll feeds are fitted to end-wheel type presses, then direct feeds must be used. When an extra long feed is required with end-wheel presses, compound gearing is necessary.

A scrap-cutting attachment for double-roll feeds can be arranged to cut off the scrap at each stroke, making it convenient to handle. Wherever possible the scrap cutter is operated from the shaft and timed a little after the press slide to give proper time for piloting.

MAGAZINE FEEDS

These are designed to feed blanks which are thick enough with respect to their area to be fed out positively from the bottom of the stack, and also to feed such stampings or low shells which can be stacked without

nesting or interlocking with each other. Included in this class of feed are those types known as coin feeds and tube feeds.

These feeds consist of a tube or magazine which serves as a containe and guide for the stack of parts to be worked, and a reciprocating slid driven from the press shaft, which pushes the parts one at a time from th bottom of the stack into the die. The magazine can be arranged t receive blanks of almost any shape although regular circles and rectangle are the most common because of complications in feeding and accuratel locating irregular-shaped blanks. Two-position feeds, and feeds with sli protection and automatic reset features, can be provided.

Location of Magazine

The position of the feed, which can be applied to practically any typ of press, may be either at the front or side of the press. Placing it at th side is usually the most satisfactory method for any of the end-whee type presses on account of the drive. For side-wheel type presses, the may be mounted either at the front or side, the conditions of the individua case being the determining factors. Adjustment can be provided fo the driving crankpin to alter the length of the feed stroke if required, but

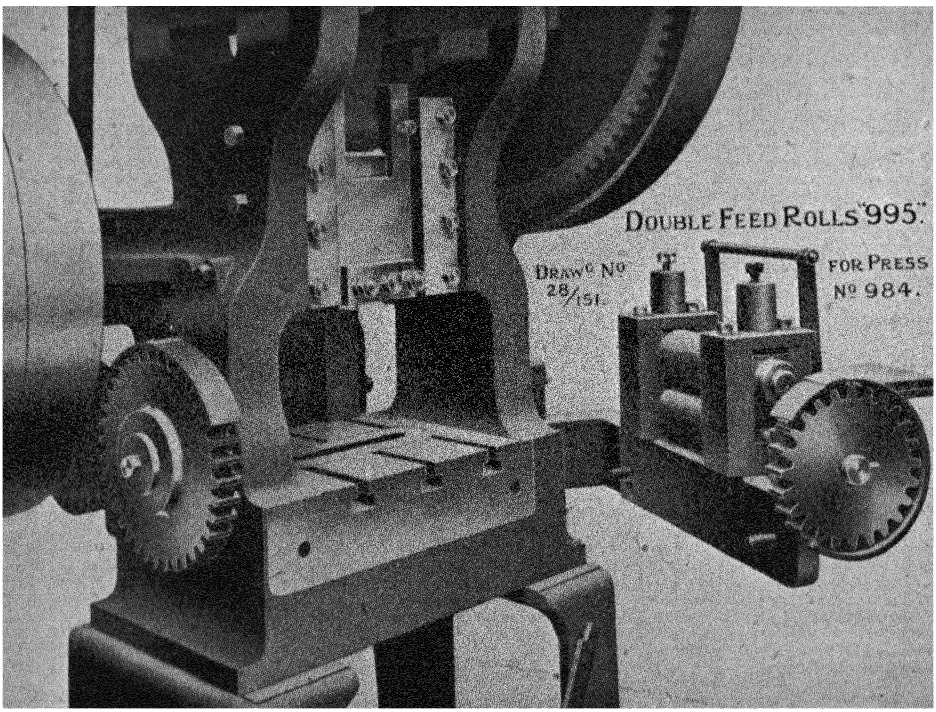


Fig. 4.—A TYPICAL DOUBLE-ROLL FEED

(*Messrs. Taylor & Challen, Ltd.*)

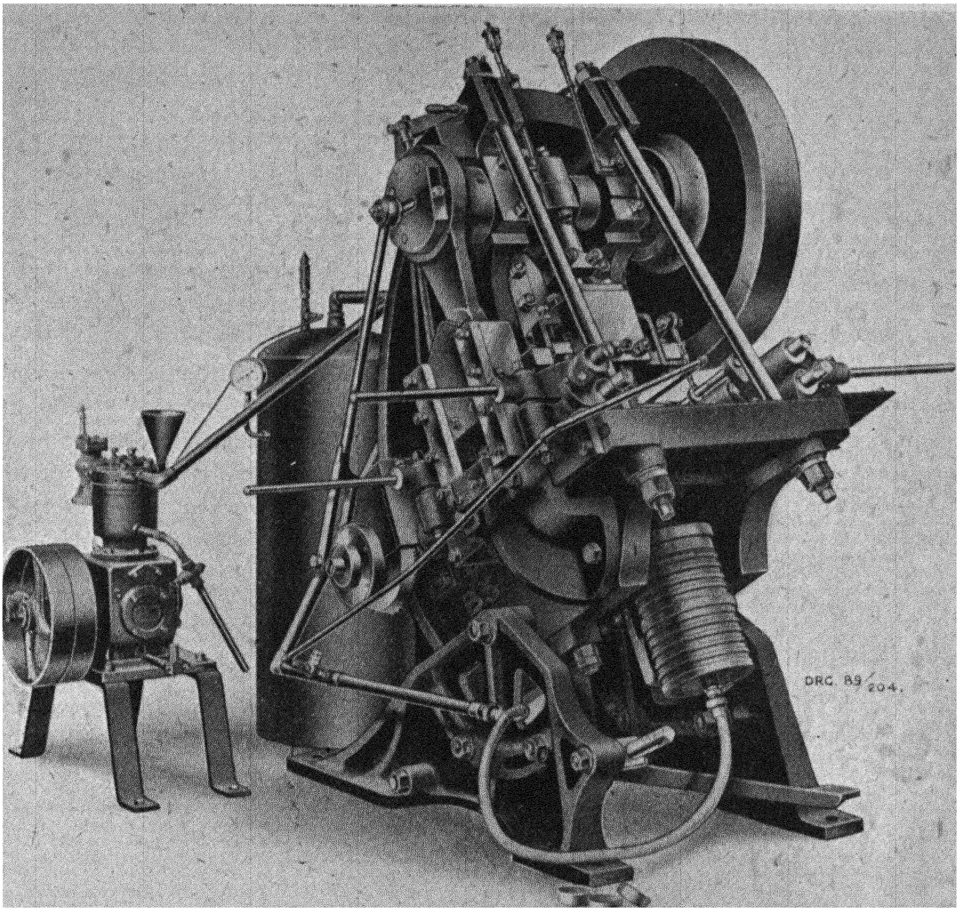


Fig. 5.—Double-roll feed press with blower and scrap-cutting attachment
(*Messrs. Taylor & Challen, Ltd.*)

as this is seldom necessary a fixed crankpin is usually provided. Hinged mountings and feed-level adjustment can also be used.

Magazine feeds are used in connection with embossing, piercing, and forming operations and also stamping, repunching, and some drawing work. It is frequently convenient, when these feeds are being used, to rig a stacking device under the press which is preparing the blanks.

PNEUMATIC SUCTION FEEDS

Suction-blank feeds and suction-strip feeds are similar to magazine feeds in that they handle blanks or strips automatically from stacks to reciprocating feed fingers. They are used, as a rule, only on highly developed machinery such as "Bliss" Automatic Strip Feed Presses and

"Bliss" Automatic Can-body Making Machines. In the former case tin plate in strip form is fed from the top of a stack to a combination die or to two dies staggered, for blanking and stamping, or forming can tops and bottoms, covers, caps, and other short shells. The presses are of the inclinable type. In the latter case tin-plate blanks cut accurately to size in a "Bliss" Gang Slitter are fed from the bottom of vertical or inclined stacks into machines for forming the bodies of tin cans.

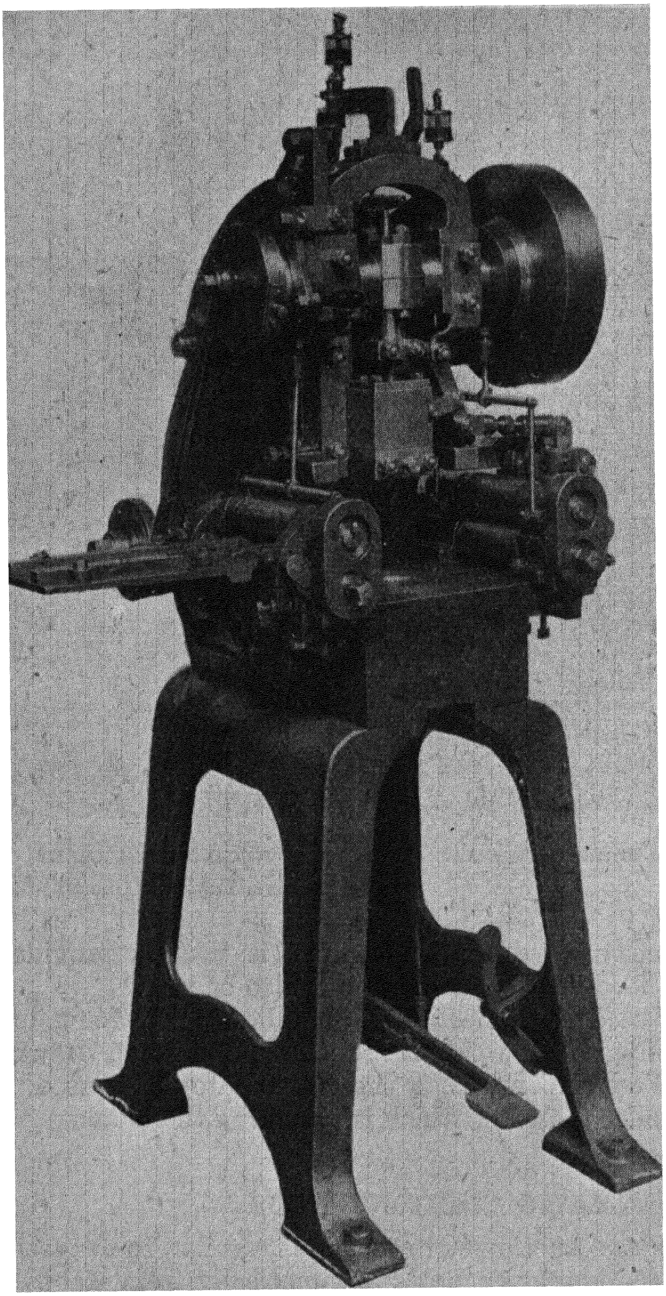


Fig. 6.—A Taylor & Challen press with double-roll feed

INDEXING FEEDS

Indexing feeds are designed to move or rotate various-shaped articles accurately under a punch or a series of punches to perforate or notch the work in accordance with whatever design may be required.

The variation in shapes and types of work, and therefore in the design of the feeding or indexing devices to do it, is greater than in any other type of feed mechanism.

On such shapes as cylindrical or conical drawn shells, only one or two lines of holes can be perforated at a time. A press for work of this character is equipped to produce automatically perforated articles such as lamp burner and percolator parts, colanders, strainers, and ornamental baskets.

For flat work, either in sheet, strip, or circular form, it is usually possible to build a single die to make all the perforations required in one stroke of the press. However, such dies are large and very expensive, especially if the shape of the hole is irregular, so that it is often much more economical to use a single row of punches and an indexing feed, particularly if the production is not large.

Indexing feeds for flat sheet work can be used for perforating square or round holes for such things as ornamental grill work, or screens, especially where varying lengths of perforation are required. They are also used for multiple punching work where a repetition of the same punching is required.

FRICTION-DIAL FEEDS

These consist of a table and a continuously revolving plain disc which, in combination with stationary guides and reciprocating fingers, feeds shells rapidly and one at a time to a die or series of dies. These feeds are particularly adapted to feeding parts, usually drawn shells, which are low enough to be in no danger of toppling over. The operator has only to push the shells from the table to the disc, with the right side up. Feeding speed ranges up to about 125 pieces per minute.

Feeds of this type are subject to modifications, depending upon the uses to which they are put. The one shown diagrammatically is adapted to such work as first and second operation redrawing. The swing arm admits just one piece, centres it under the punch, and holds it until the slide descends. In this case the work is pushed through the die although knock-outs, ejectors, or conveyors can also be provided. The friction dial is also used in connection with positive cam-actuated gripping fingers, one pair carrying the shell from the dial to the die and another pair removing it. If more than one operation is being performed, fingers are arranged to carry the shell accurately to the several stations.

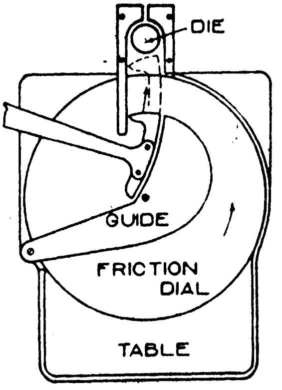


Fig. 7.—FRICTION-DIAL FEEDS

Friction-dial feeds are also much used with multiple-slide presses. That is, where a series of operations, say five or seven, are to be performed on a previously blanked and cupped shell, the friction dial is used to start the shell which is then carried on from die to die by means of a lateral feed.

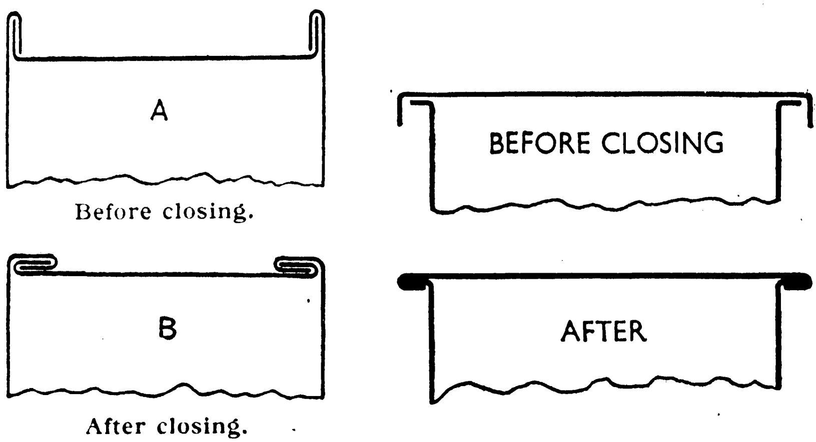


Fig. 8.—Two different closing operations on a dial-feed press

DRUM FEEDS

These are modifications of dial feeds, although they are frequently driven by geneva stop motions instead of by ratchet. The work is fed in at the front of the drum, carried to the top where the operation is performed, and the work discharged at the back.

These feeds are particularly adapted to performing piercing, trimming, and forming operations on comparatively deep work or on pieces having a stem or shank on them.

This type of feed can, of course, be applied to many different styles of presses but is particularly applicable to the straight-sided presses and the adjustable bed presses. Where the production warrants it, as when the press is to be used only on the one type of work, the greatest rigidity and satisfaction usually results from building the feed right into a press of the straight-sided type. However, when the size of the work will permit, it is sometimes desirable to have the feed in a separate unit which can be removed, leaving the press open to use as a standard machine.

RATCHET-DIAL FEEDS

Dial feeds of the ratchet type are adapted for secondary operations such as redrawing, piercing, stamping, broaching, wiring, punching, and burring or other operations on blanks or shells which have been previously blanked and drawn. They may also be arranged in some cases to perform two or three operations in sequence in one press. In such cases it is advisable to balance the operations so that the strain on the slide will not be much off centre and to provide separate adjustment for height on the punches. Dial feeds are also used for many assembling, riveting, and closing operations on finished parts and on material other than metal.

The operator places shells in the bushings or on the posts at the front

of the dial, from which point they are carried around into alignment with the punch or punches and, after the operation, are carried further and mechanically ejected or picked off. With these feeds an unskilled operator can catch every stroke of a press operating continuously at full rated speed.

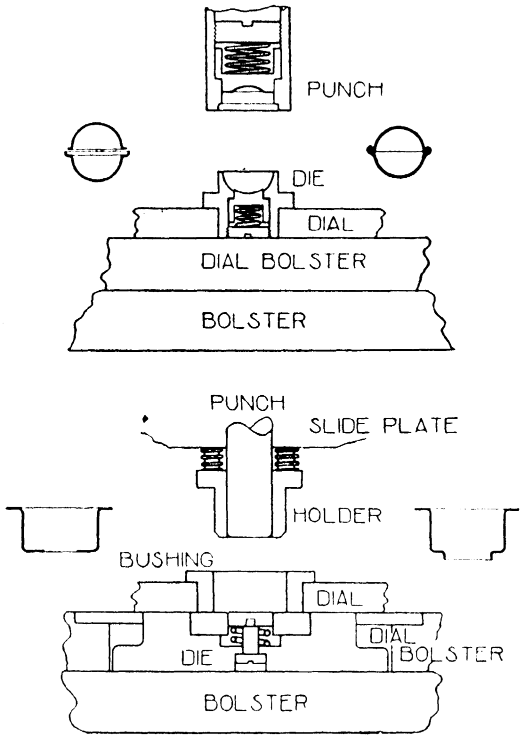


Fig. 9.—Showing two different arrangements of dies with ratchet-dial feeds

Fully Automatic Types

To make them fully automatic, dial feeds of this type are sometimes arranged with chute or hopper feeds to supply the shells to the dial stations or they may even be fitted with roll feeds to handle the strip from which the shells are blanked and cupped preparatory to other operations in the dial.

The diagram (Fig. 9) shows two different arrangements of dies with dial feeds. As shown at the top, a simple closing operation, the die may be entirely carried on the dial. In the lower diagram, a burring operation, the die is located entirely in the dial bolster, and after the operation the shell is returned to the bushing in the dial which acts only as a means of carrying it around. Redrawing operations, in which the die is in the bolster and the work is pushed all the way through, are modifications of the latter type. Cutting-edge operations should always be arranged with the die in the bolster under the dial.

Ratchet-dial feeds are built into two types as regards driving power, one being crank-operated and the other cam-operated. Crank-operated dial feeds are standard. There is, however, certain work which requires cam-operated feeds.

The stroke of the crankshaft on presses arranged with dial feeds should be twice the distance that the punch enters the dial bushing and die plus $\frac{1}{4}$ inch.

Chapter III

GUARDS AND SAFETY DEVICES

ACCIDENTS between the tool and the die on power presses average just over two per working day throughout the year. The number is not large and, indeed, appears insignificant in comparison with the figures returned for road-casualties. But the accidents with power presses differ from those met with in other activities because they almost invariably result in permanent disablement.

Little can be done, even by expert surgical treatment, when a punch which deals with quarter-inch metal has come in contact with flesh and bone. That is why the subject of guards has closely engaged the authorities for many years and probably more care and thought have been given to devising adequate safety measures for power presses than for any other machine in industry.

Despite the preference for the fixed type of guard expressed by the Factories Act (1937), the automatic principle has always strongly appealed to power-press users, and a large number of clever automatic guards have been introduced for these machines. It has to be recognised, however, that some have failed—simply because they have satisfied neither the needs of accident prevention nor the legal requirements.

The Legal Requirements

Section 14 (1) of the Factories Act of 1937, which is the law on the subject, relates to the fencing of dangerous parts of machinery and contains a proviso of great importance to power-press users, which says: "Provided that, in so far as the safety of a dangerous part of any machinery cannot by reason of the nature of the operation be secured by means of a fixed guard, the requirements of this sub-section shall be deemed to have been complied with if a device is provided which automatically prevents the operator from coming into contact with that part."

Fixed Guards and Automatic Guards

In general, it may be said that the Factory Inspectorate branch of the Home Office holds that the fixed guard should be much more widely used.

This attitude is not based on the assumption that, provided skill and ingenuity are employed, any press operation, no matter how large or complicated, can be carried out under the protection of a fixed guard. Such a contention, if true, would imply that automatic guards are used to-day

on many presses which could—and therefore should, if the law is to be complied with—be fitted with fixed guards.

With regard to heavy presses, the Chief Inspector of Factories, in accordance with well-established practice, set up a small committee on which sat representatives of press users alongside the representatives of the Factory Department of the Home Office. There was an attitude of co-operation and a frank facing up to the problems involved and examination of the steps that had been taken to overcome the difficulties. Whilst it was always kept in mind that the Factories Act clearly states that the fixed guard is the only type acceptable if it is practicable, it was also recognised that on heavy machines the nature of the operations made other devices necessary. The idea of formulating a special code of Regulations to control the guarding of heavy presses was not favoured, it being held that such a code was not advisable since the dangers to be met, and the best methods of overcoming them, were not obvious enough to justify the enforcement of rules which might still prove ineffective.

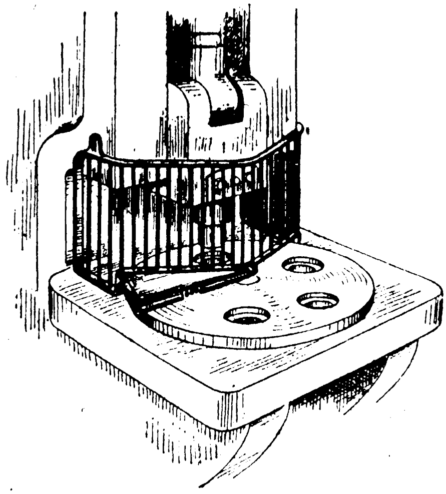


Fig. 1.—GUARD FOR DIAL-FEED OPERATIONS

Access to the danger zone is prevented by this fixed guard which has a rubber-covered spring fitted at a distance in front of the left side of the guard equivalent to not less than each movement of the turntable. The operator is thus able to withdraw a finger from the turntable recess before it becomes trapped against the lower bar of the guard. The space between the rubber-covered spring and the lower edge of the guard is covered by a flexible flap.

The whole subject was in the fluid and formative stage, and more harm than good might be done by such a procedure; for what was wanted was experiment and research so that the best methods of working and the best design of guards should be achieved. This proved to be an extremely sound view, and although there is still a long way to go, the investigations and the practical co-operation of various pioneering firms have made it quite clear that the policy of using fixed as opposed to automatic guards could be extended without paralysing production or at least so seriously reducing output that major economic problems would result. The importance of the fixed type of guard as a safety device in industry cannot therefore be over-estimated.

Fixed Guards and Feeds

It may be said that in the past fixed guards have been largely confined to operations on the strip. When a combined operation such as cut and

cup is performed, from strip, a specially designed chute is often necessary for the delivery of the work without infringing the legal requirements. This method of fencing is now being considerably developed for work on components which need to be placed on the die. The simplest method from the tooling angle is to provide for feeding through a fixed guard by means of tongs or special grippers (Fig. 3). Other methods of feeding the work are chute feeds, slide feeds, and sliding dies. Thus, where a cupped article has to be given a second draw, a horizontal or inclined chute, fed through a fixed guard, is appropriate (Fig. 13). If the work is stripped off the punch, a compressed-air nozzle can be used for stripping it off the die, and if applied in conjunction with an inclined table so that the finished work falls into a receiving bin by gravity, a speedy production set-up with a maximum of safety is ensured. For handling flat blanks for forming, slide feeds are very useful, or for formed articles for piercing, when nest location is in use. The fixed nest in the die

Fig. 2.—FORMING A "U"-SHAPED BRACKET FROM THE BLANK
(*Ford Motor Co., Ltd.*)

The component after bending is seen on the left of the die. The danger to the operator working at this type of unguarded press is apparent from the photograph.

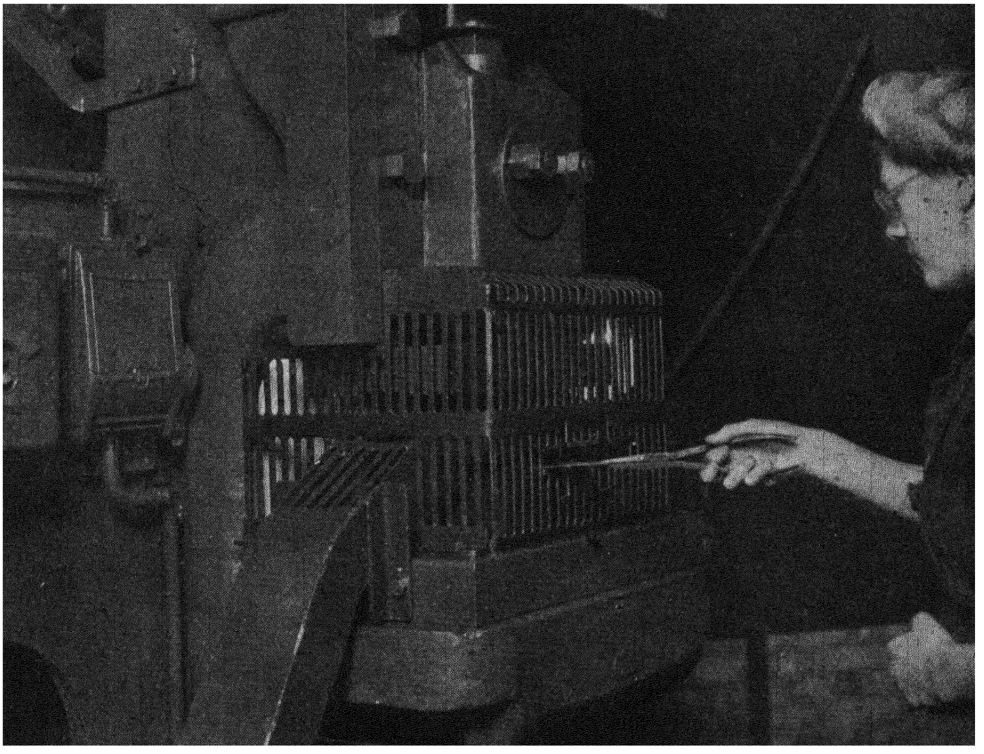


Fig. 3.—THE PRESS SHOWN IN FIG. 2, WITH A FIXED GUARD ATTACHED
(*Ford Motor Co., Ltd.*)

The blank is inserted at the front and passes out through the side chute after bending.

surface is replaced by a sliding plate cut out to the component shape and mounted in a slide with suitable locating stops. The slide plate should be made of soft material so as to minimise the risk of damage to punches, should the press be prematurely tripped. In the case of punching operations, a constant progress of work with conditions amounting to continuous-flow production can be attained with the use of a simple power-operated push feed in conjunction with a slide. The drive for this can be obtained by suitable fittings on the dies. Dial feeds are eminently suitable for large-scale production jobs and can now be seen in use on large work such as cartridge cases. Operations on cupped articles such as heading and forming are suitable for treatment in this way. Even when presses are not specially designed for dial feeds, hand-operated dials are often successfully applied and give excellent production figures with greatly increased safety. In fact danger can be completely eliminated. The advisability of obtaining dial-feed facilities is a point that should be kept in mind when installing a new press.

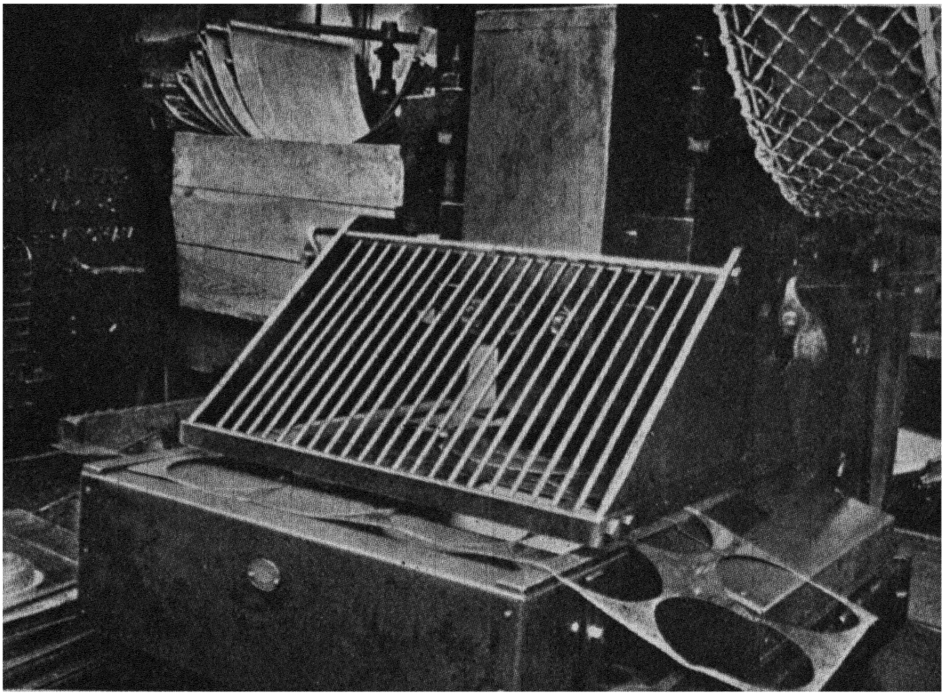
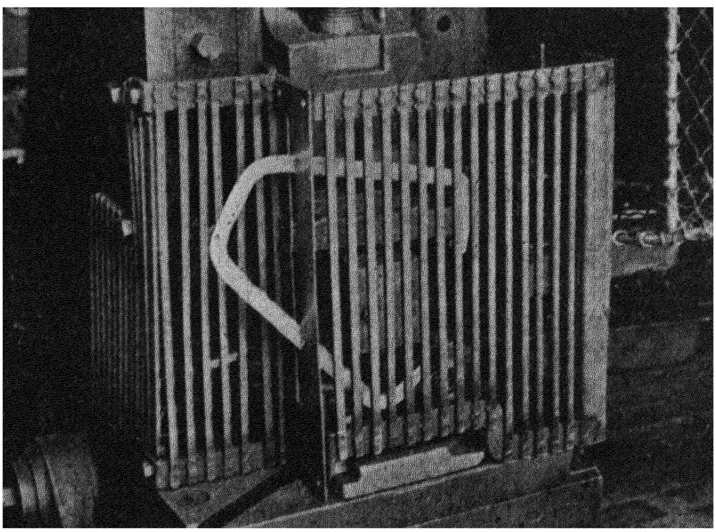


Fig. 4.—A GUARD USED DURING COMBINED BLANKING AND CUPPING OPERATIONS (*Taylor Law and Co. Ltd.*)

The formed article is pulled forward with the strip and falls through an opening in the press-table into a basket below. The opening is visible below the guard on the right.



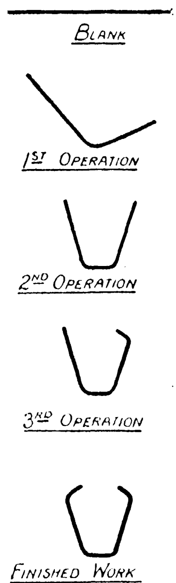


Fig. 5.—A FIXED GUARD USED IN THE TYPE OF MULTIPLE BENDING OPERATION ILLUSTRATED ON THE RIGHT (*H. Terry & Sons Ltd.*)

This guard prevents access to the tools and dies, while allowing the work to be viewed.

The use of sliding feeds in conjunction with fixed guards has also been greatly developed by certain manufacturers who, whilst setting a high standard on their production figures, are fully alive to the value of ensuring safety for the operative, or of at least eliminating as many avoidable contingencies as possible. There is, of course, the additional cost to be faced in the initial installation, such as is involved in providing a sliding sub-table, but there is little doubt that whether viewed from the production angle or the safety angle, the investment is a good one. With this method the work in hand is loaded and removed from the die at a point situated conveniently in front of the operator. This obviates the

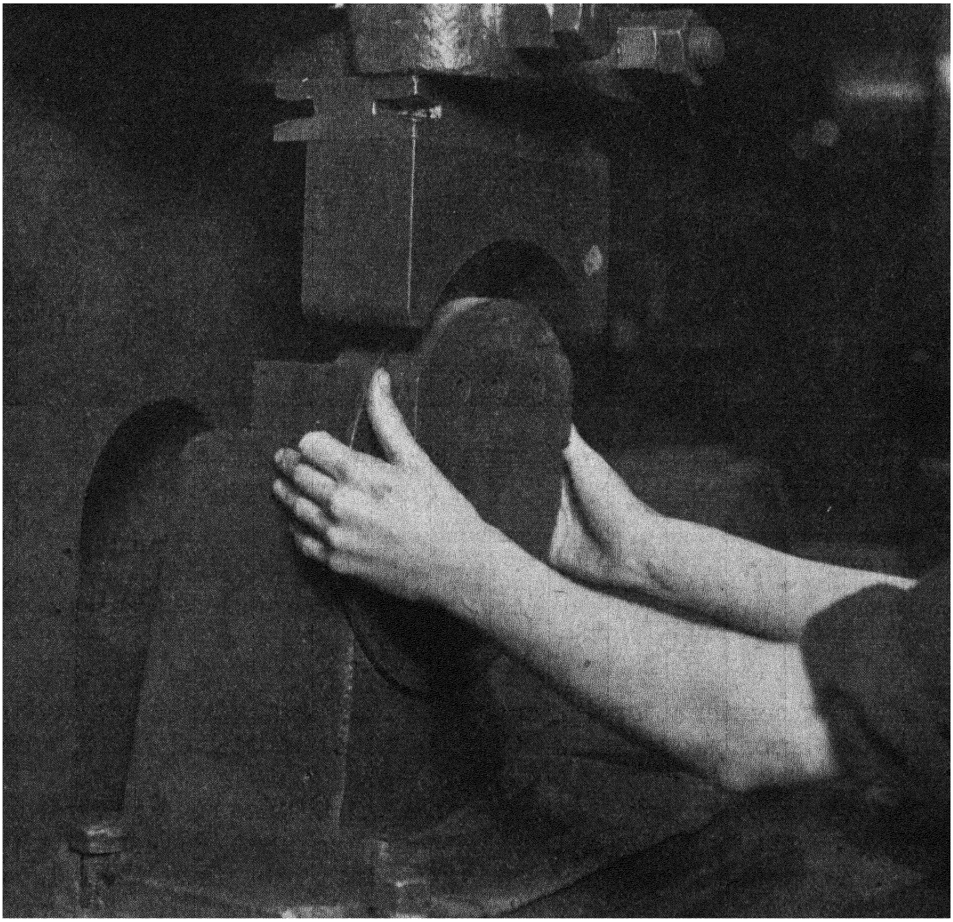


Fig. 6.—FINISHING A STARTER-RING-GEAR BLANK TO A TRUE CIRCLE IN AN UNGUARDED PRESS

(*Ford Motor Co., Ltd.*)

Several strokes of the press are required while the ring is being turned round in the groove in the lower die, and every stroke is a threat to the unprotected hands.

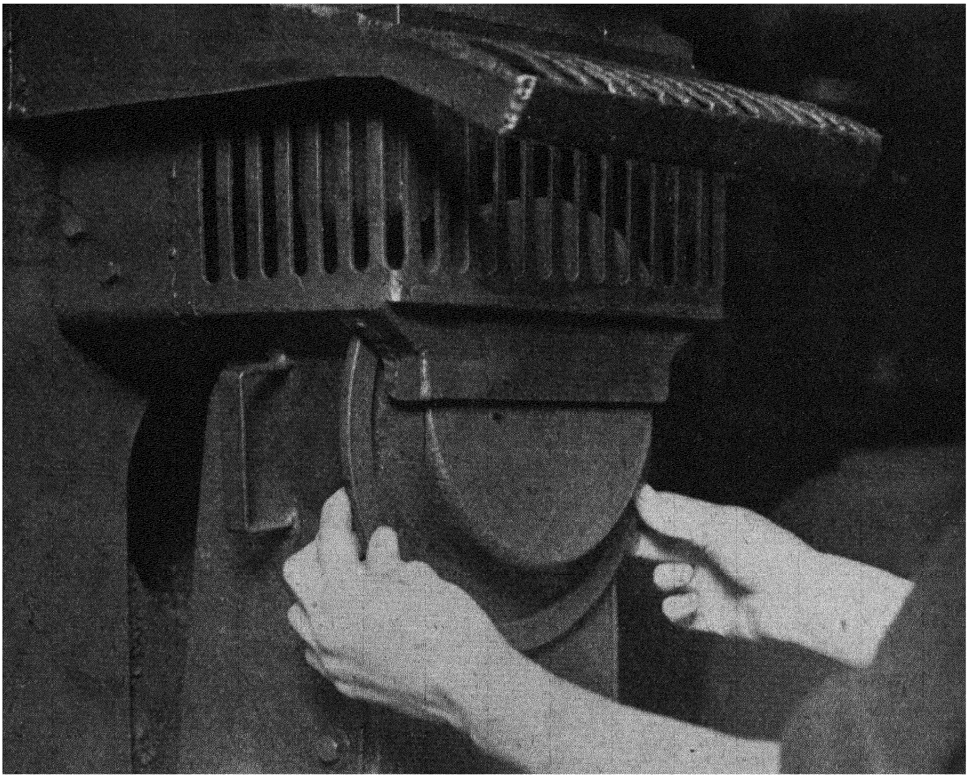


Fig. 7.—The press with a fixed guard and adjustable flap

(*Ford Motor Co., Ltd.*)

The upper guard is fixed to the press column and the lower portion is hinged on two screws, one seen hinged below the left hand. The component is raised out of the groove, and in bringing it forward the guard moves with it. When in its forward position the component falls clear of the slot in the guard. The guard remains in the forward position while the next component is inserted.

necessity for continual leaning and stretching—an undesirable waste of effort that becomes extremely tiring after a comparatively short space of time.

It is important enough, even under normal working conditions, that a press operator should at all times be fresh and alert. When an extra effort is demanded, such as the strain imposed by overtime, the value of any device whereby human energy can be conserved is to be greatly valued, for in addition to the considerations of safety and production previously mentioned, it helps to maintain the general well-being of the worker.

There is a good deal of wisdom in the old saw which says that "Men as well as machines can break down."

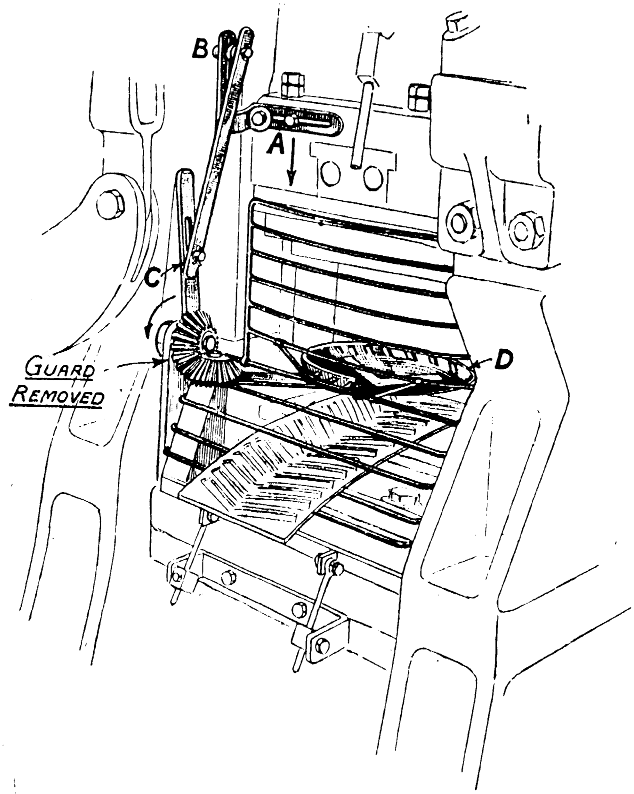


Fig. 8.—A FIXED GUARD WITH EJECTING TRAY TO REMOVE PRESSINGS

The necessity for the removal of the pressings or scrap often prevents the use of an efficient fixed guard. In the device shown the difficulty is overcome for certain work done on a 5-in.-stroke press. On the up-stroke of the ram, the tray D passes through the opening in the fixed guard and the pressing drops off the stripper plate into the tray; as the ram descends the tray moves out again and the pressing slides from it into a bin. Note the adjustments at A, B, and C to permit of accurate timing in relation to the stroke of the press.

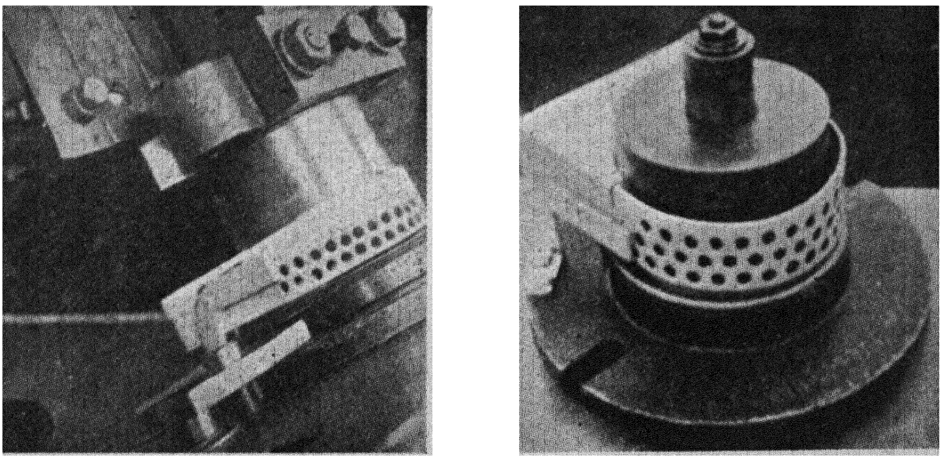


Fig. 9.—FIXED GUARD

The front and sides of the tool and die are surrounded by a perforated screen which is extended in the form of a tunnel (completely enclosed) through which the cupped work falls to the rear of the press.

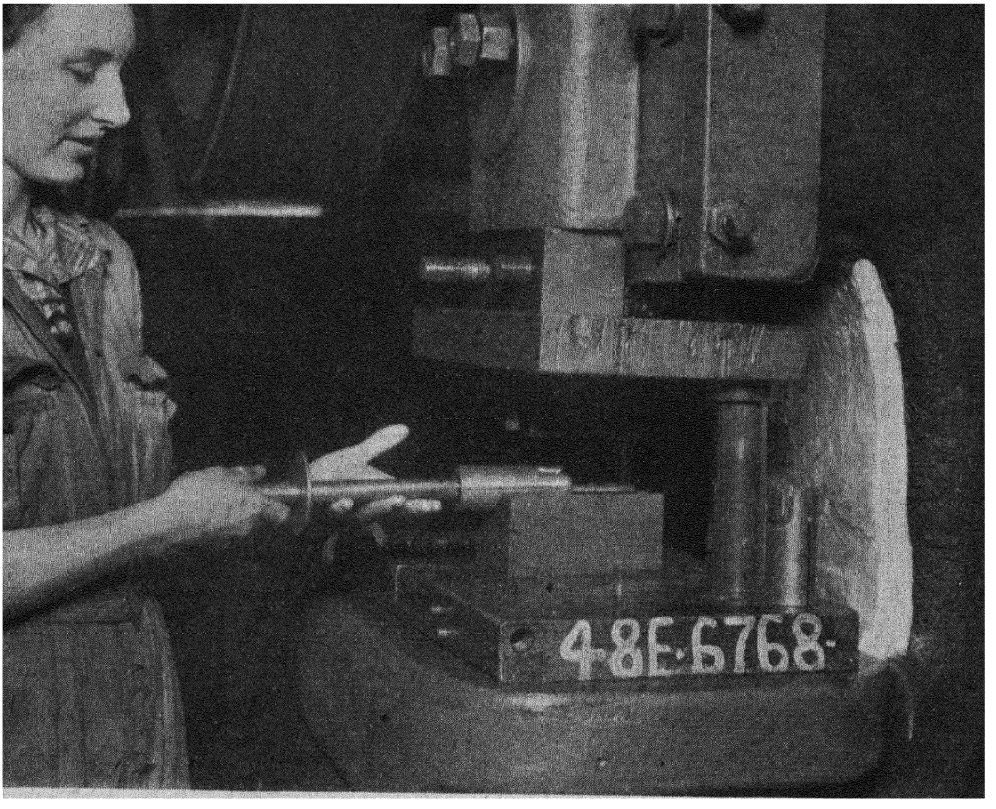


Fig. 10.—FORMING A BAYONET SLOT IN A TUBE LOCATED ON A LOOSE MANDREL
(*Ford Motor Co., Ltd.*)
The press has no guard, and the operator's left hand is near the danger zone.

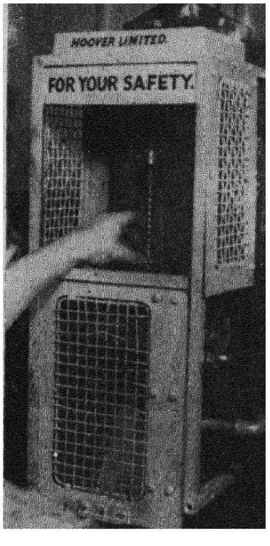


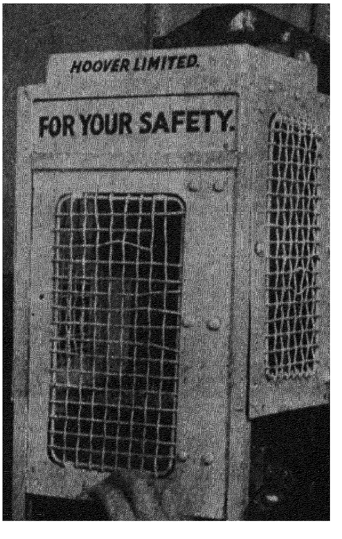
Fig. 11.—VERTICALLY SLIDING SAFETY GATE

The handle seen in the bottom right-hand corner is in a neutral position. Moving it upwards or downwards places it in the "stroke" and "return" positions respectively. The handle will automatically return from the lower position to neutral when head is fully returned.

Fig. 12.

The gate can only be opened as shown in the photograph when the handle is in the neutral position.

(*Hoover Ltd.*)



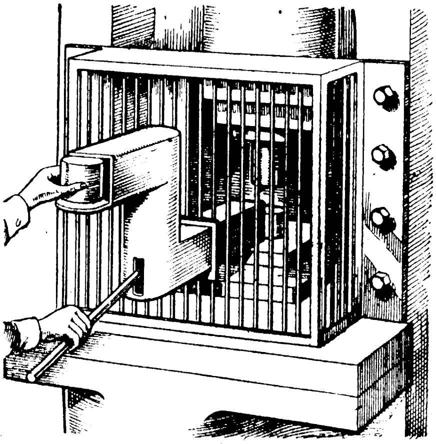


Fig. 13.—Chute feeding

Shows a method of chute feeding which effectively shields the operator from the press while allowing an article to be fed to the die. It overcomes the difficulty which arises when, in order properly to perform the operation of feeding partially formed articles to the die, the fixed guard would require an opening large enough to permit the hand to enter the danger zone.

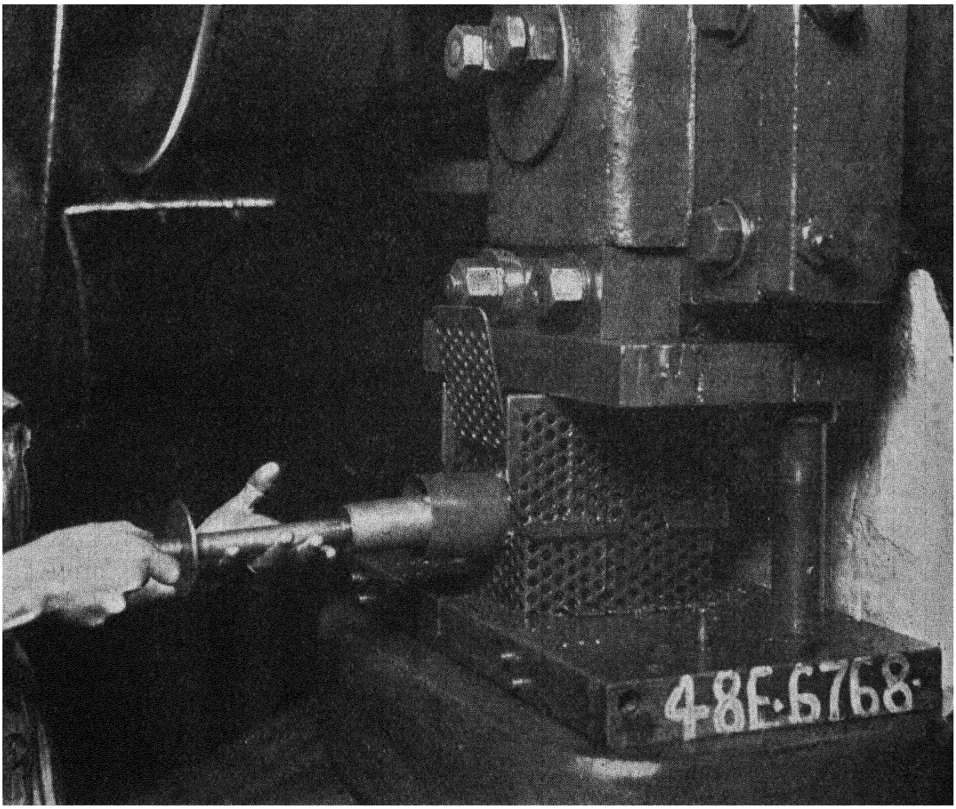


Fig. 14.—The operation shown in Fig. 10, but using a fixed guard
(*Ford Motor Co., Ltd.*)

The component is placed on a mandrel and both inserted into the die through a tube. The main guard is attached to the die shoe and the side plates to the punch holder.

In Fig. 15 and Fig. 16 the operation of slotting circular birdcage bases is being performed.

To design a satisfactory fixed guard to cover this operation was found to be extremely difficult, but after some experiment the guard illustrated was successfully evolved.

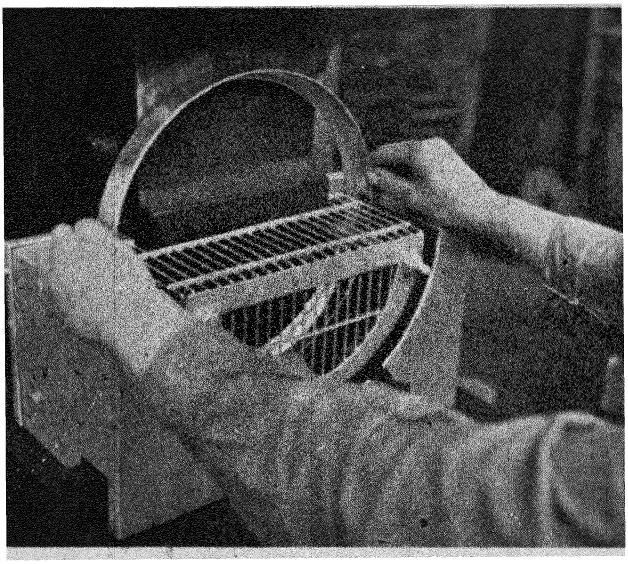


Fig. 15.—FIXED GUARD USED FOR SLOTTING OPERATION (*Hygienic Wire Works Ltd.*)

A circular birdcage base ready for slotting.

It might be expected that such a guard, while affording satisfactory protection to the operator, would reduce output. In actual practice it was found that work carried out under cover of this guard resulted in increased production. This increase was accounted for by the fact that the operator could rest both hands on the guard during the operation and with the aid of the two locating pegs on the front of the guard obtain accurate location for the cage base in a minimum of time.

An additional factor, contributing in some degree to the increased output claimed by the designers of the guard, is the facility with which the cage base can be removed from the machine once the slotting operation has been performed.

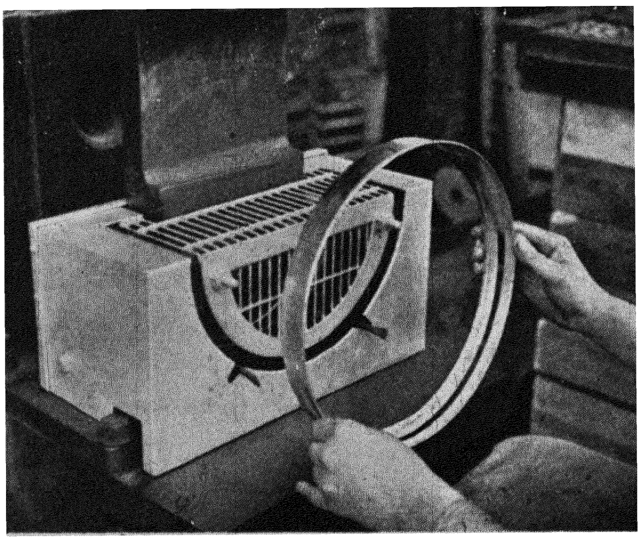


Fig. 16.—THE OPERATION COMPLETED AND THE BASE WITHDRAWN (*Hygienic Wire Works Ltd.*)

Note the two pegs to assist accurate location.

Interlock Guards

The occurrence of a not inconsiderable number of accidents on short-stroke presses equipped with automatic guards has caused some doubt as to their efficacy under certain conditions. In consequence of this, interlocked fixed guards, which makers of power-press guards are equipped to supply, are used. The principle underlying these devices is that all access to the danger area must be cut off before it is possible

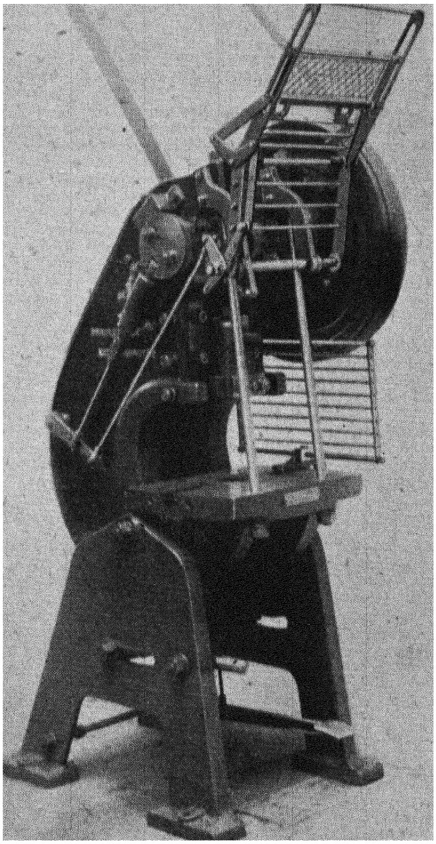


Fig. 17.—INTERLOCK GUARD SWUNG CLEAR FOR TOOL-SETTING

(*J. P. Udal*)

The guard requires no adjustments and can only be set in two positions—the working position and the tool-setting position. The guard is positively held in either position by a bolt locking the guard frame to one of the carrying brackets.

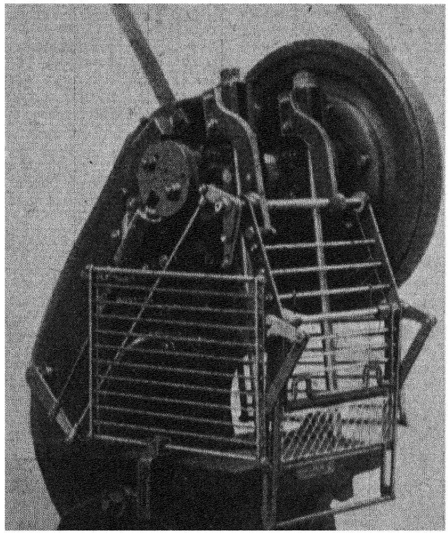


Fig. 18.—GUARD CLOSED WITH SCOTCH WITHDRAWN FROM CRANKSHAFT

(*J. P. Udal*)

The guard consists of a double shutter with rising and falling members which open to give a large aperture through which the operator feeds the press tools. In the closed position the shutters completely prevent access to the tools from the front of the press. The shutters are carried in main arms which are held rigidly in position, and form a convenient anchorage for side guards, which are carried round the sides of the press, thus entirely preventing access to the tools from any direction. With the guard closed; and the scotch withdrawn from the crankshaft, the press is free to operate and further depression of the clutch pedal will engage the press clutch. This type of guard interlocks with the clutch key extractor in a way that prevents the press operating while the guard is in its open position.

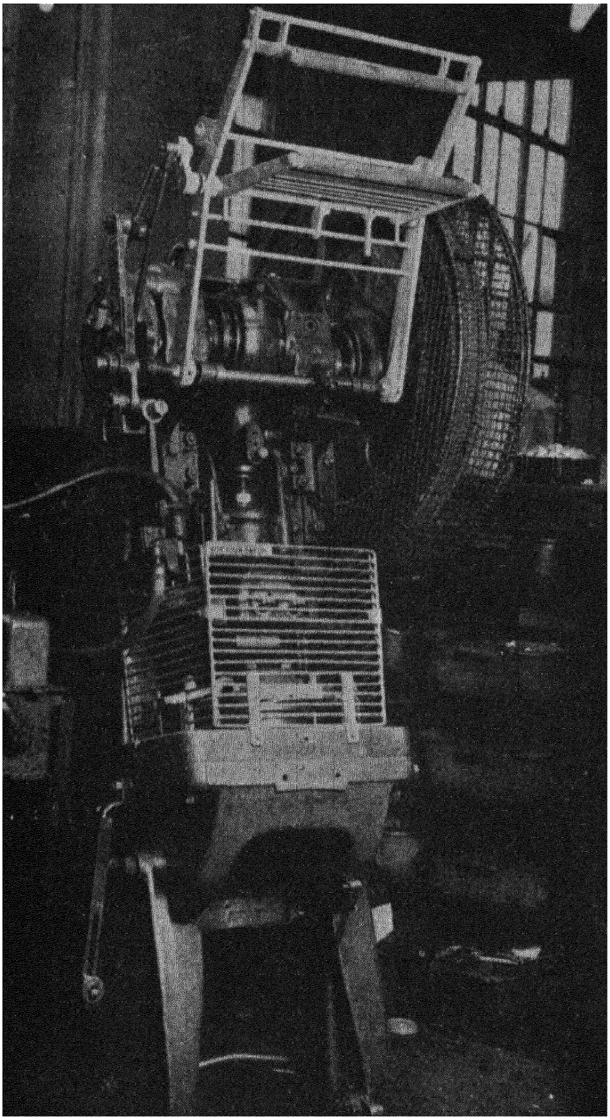


Fig. 19.—A FULLY GUARDED POWER PRESS
(*Hoover Ltd.*)

The fixed guard is in position for strip work, while the interlock guards are shown swung clear.

to set the press in motion and that the fencing should be maintained until the press has come to rest. When these guards are used, careful routine examination of clutches and routine maintenance of both clutches and drives are necessary to obviate the risk of key failures or flywheel seizures leading to uncovenanted repeats. Press-guard manufacturers can give sound advice based on varied experience as to the class of presses on which automatic guards should not be used.

Where variable-stroke presses are concerned, particular care is needed in the application of automatic guards. Most of these presses are calibrated in such a way that the reduction of stroke is achieved by the rotation of the eccentric in the direction of crankshaft rotation. Since the automatic guard is driven by the crankshaft it will be realised that on intermediate strokes the timing of the guard will be adversely affected. By the simple device of reversing the calibration so that the eccentric is rotated contrary to the direction of the crankshaft, improved timing is gained at intermediate strokes.

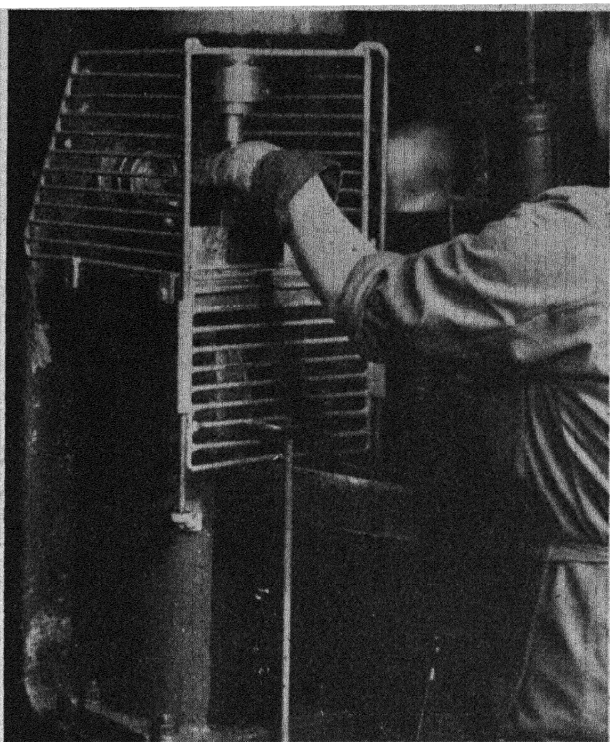


Fig. 20.—AN ELECTRAULIC PRESS WITH AN INTERLOCK GUARD

(*Hoover Ltd.*)

The open guard with the operator's hand beneath the ram shows the obvious danger. The machine cannot be operated until the gate shown closed in Fig. 21 has been locked in position.

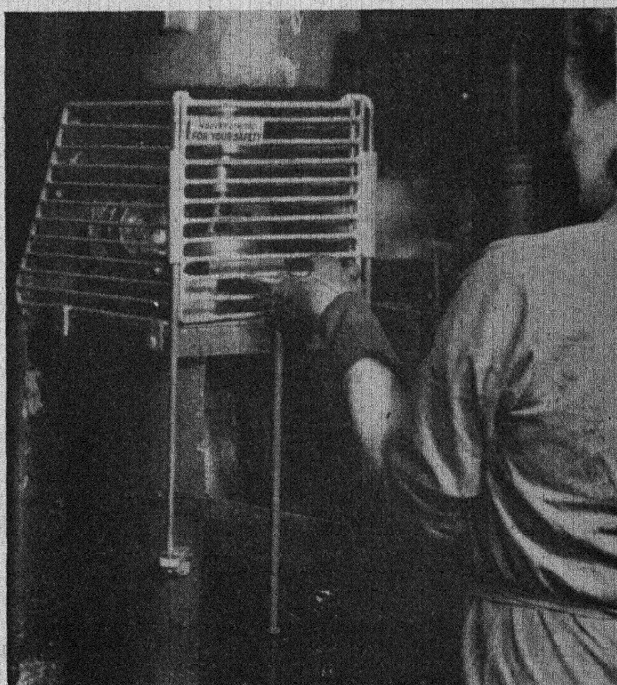


Fig. 21.—THE WORKING POSITION OF THE GUARD SHOWN IN FIG. 20

(*Hoover Ltd.*)

With the guard in this position all possibility of accident to the hand or fingers is eliminated.

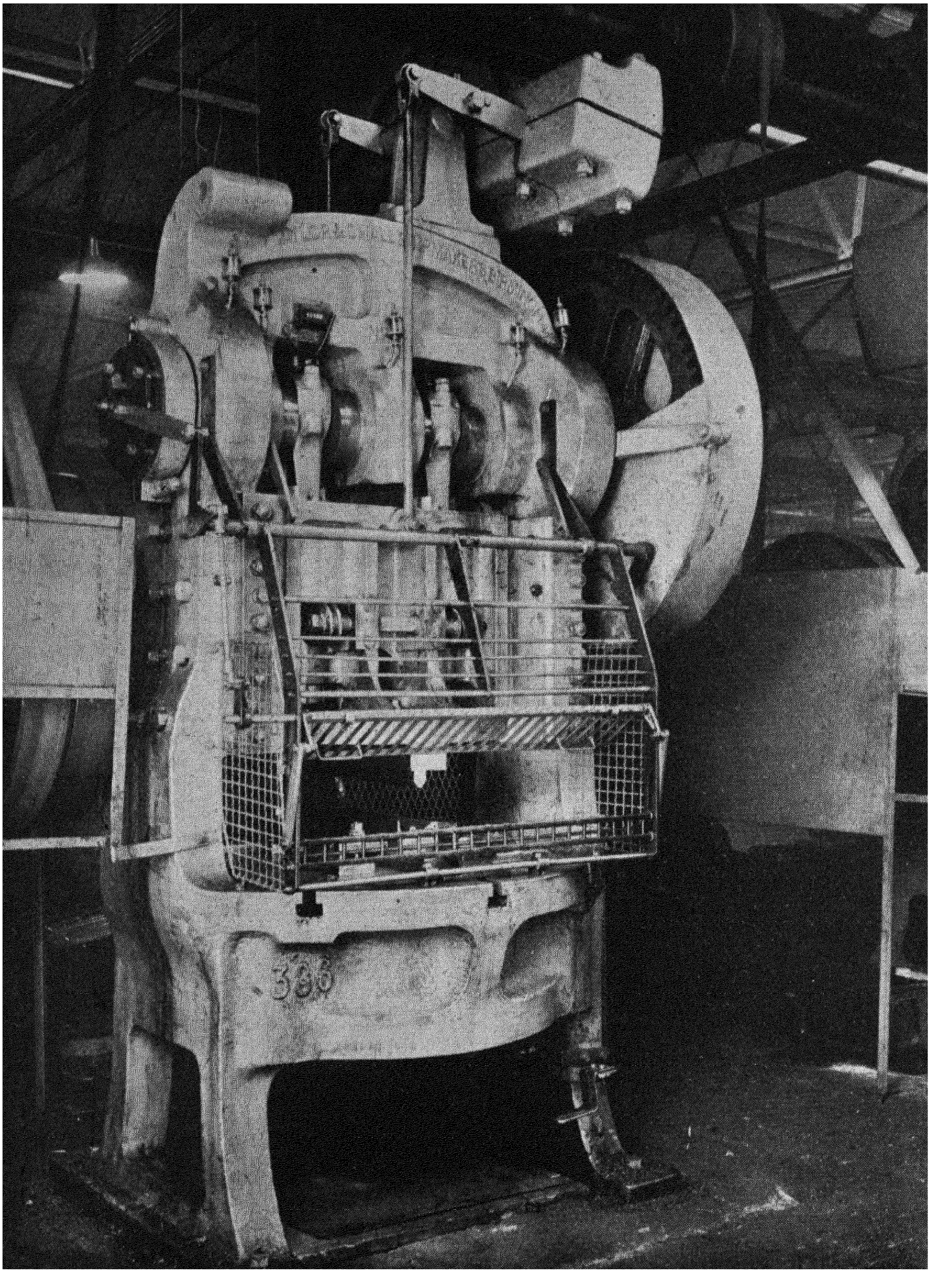


Fig. 22.—Interlock guard fitted to 100-ton double-crank press
(*Press Guards Ltd.*)

This type of guard is manually operated and is designed to prevent the operator setting the machine in motion until the guard has been fully closed.

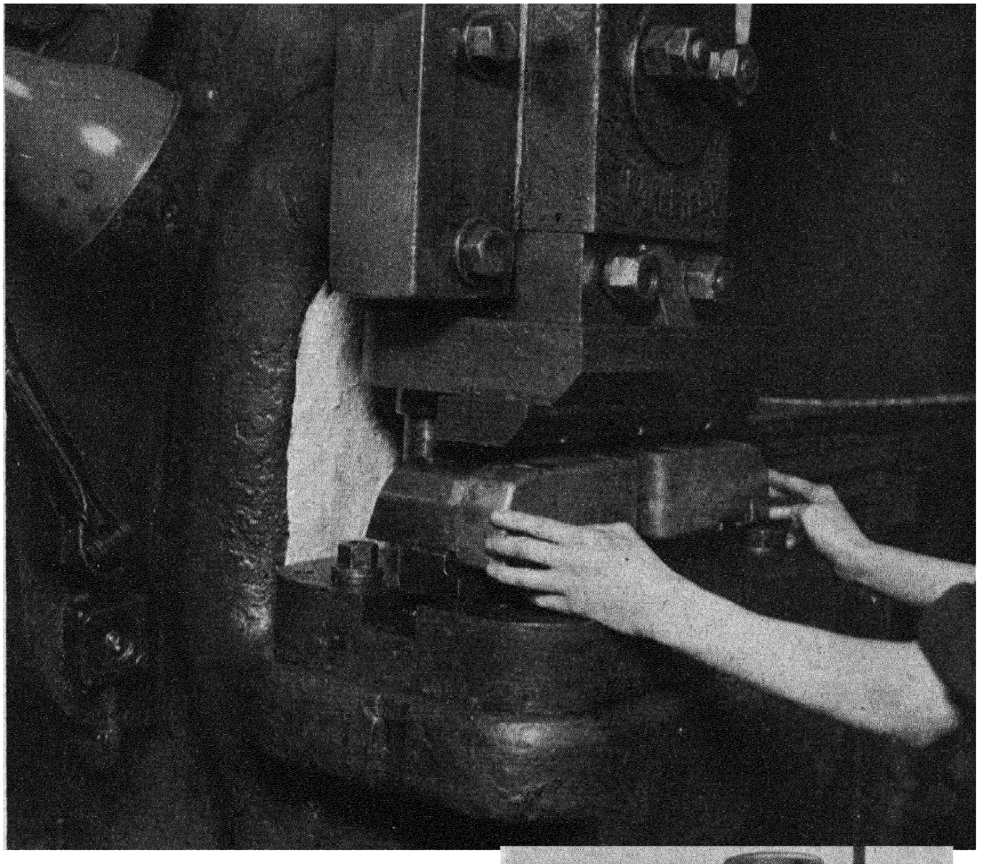


Fig. 23.—EMBOSSING A RADIATOR WATER TANK

(*Ford Motor Co., Ltd.*)

The press has no guard and the position of the operator's hands indicates clearly the ever-present risk of accident.

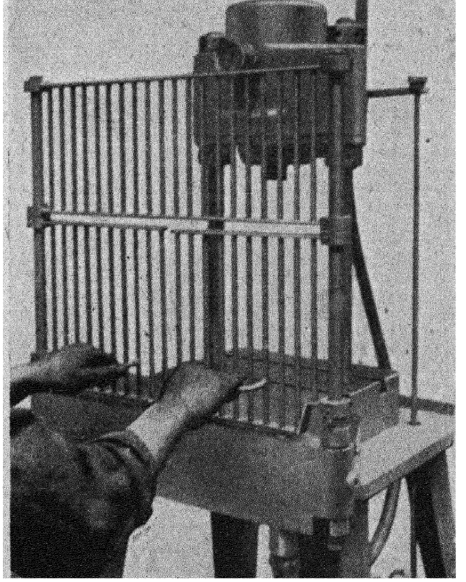
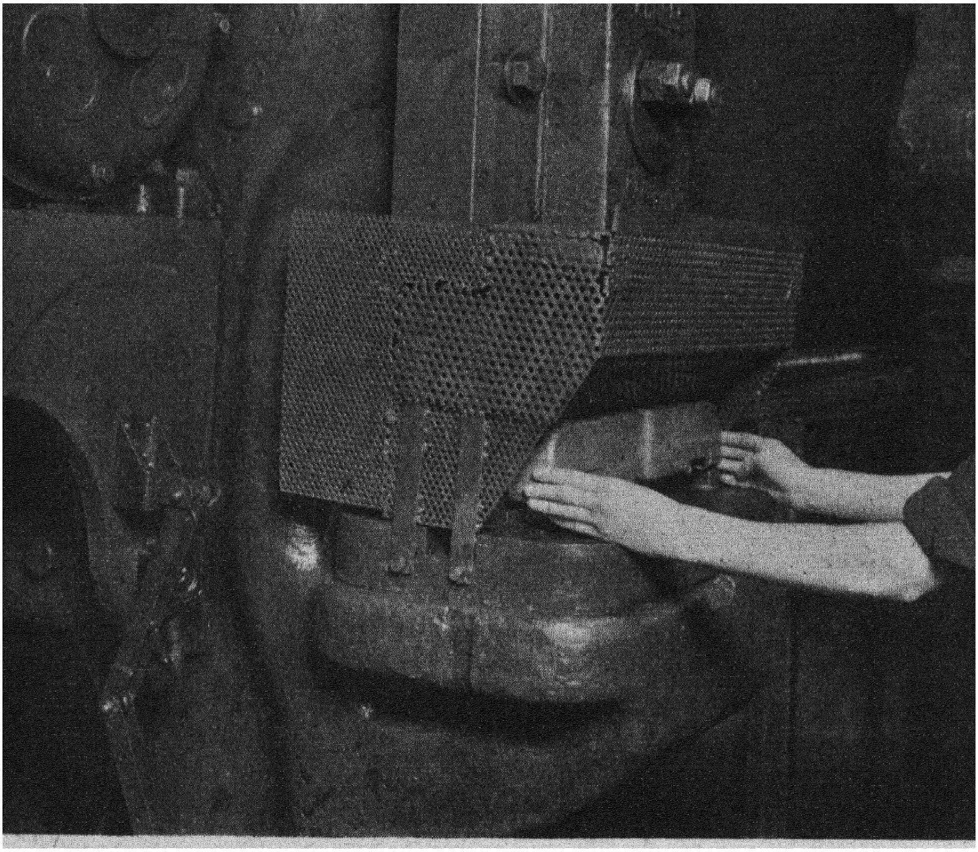


Fig. 24.—HAND-CLOSED GUARD

(*Jackson & Hunt and E.M.B. Co. Ltd.*)

In operation, the component is placed in the guard, and in withdrawing the fingers are hooked into the gate handles and the gates closed as shown. Interlocking mechanism prevents the press from operating until both gates are shut.



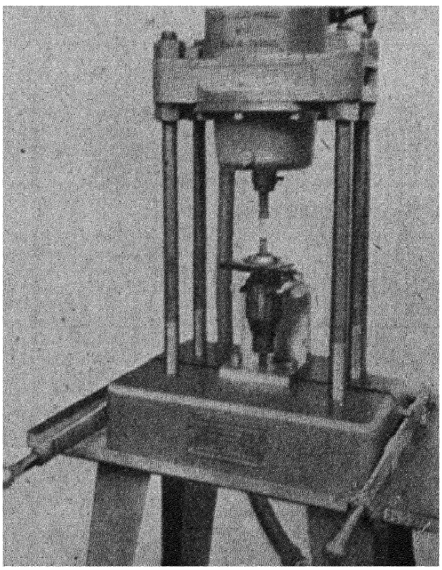


Fig. 25.—PERFORMING THE OPERATION SHOWN IN FIG. 23, BUT PROTECTED BY A FIXED GUARD

(*Ford Motor Co., Ltd.*)

By reducing all clearance between the component and the guard to a minimum, it is possible to withdraw the component after embossing and still exclude the fingers.

Fig. 26.—SAFETY CONTROL HANDLE

(*Jackson & Hunt and E.M.B. Co. Ltd.*)

Both hands are needed to operate the press shown on the left. Either handle operated alone will have no effect.

Automatic Guards

Where sufficient space is left on the bolster or bed of a press outside the area of the die, it is imperative, where the space thus left is sufficient to accommodate a worker, to screen and guard adequately against access. When a press is at rest, with the driving mechanism in motion, no work should be done between tools and dies unless supports are placed so as to prevent descent of the ram.

Above all—and the importance of this is beyond all question—no press operative engaged in active production work in the shop should work on a press unless it is provided with properly functioning safety devices which are in sound working order. If the tools used in a particular press job call for adjustment of the safety devices, the adjustments made must not interfere with proper working or efficiency. Moreover, the device which is used to secure safety should also ensure that the operative is, by means of a moving member, screened off or removed to a safe distance before the gap between the nearest trapping parts closes to less than 5 in. The moving member of the safety device should be at a height of not less than 3 ft. 6 in. above the standing place of the operative when the press ram is at the top of its stroke. During the actual stroke, access to the bolster area below this height should be prevented by screening.

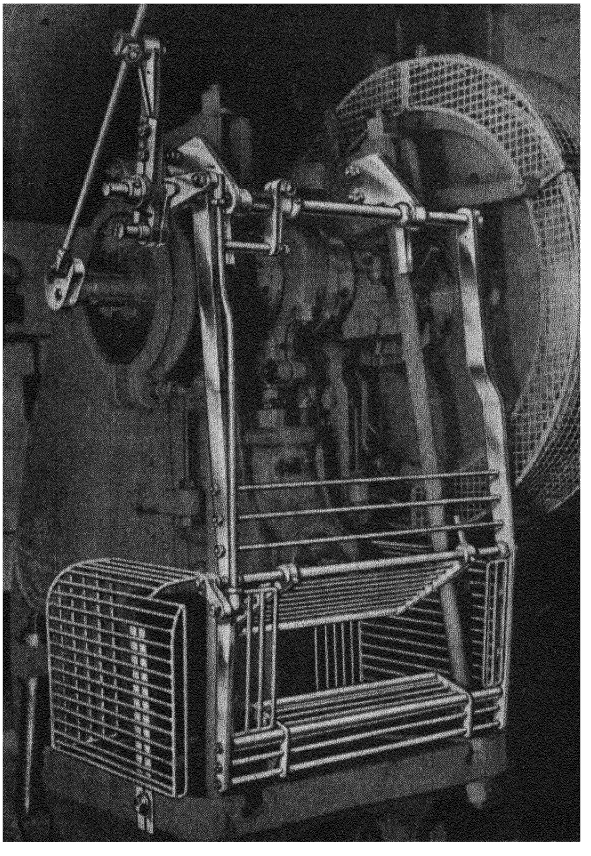


Fig. 27.—" PUSH-OUT " AUTOMATIC GUARD

(*J. Broughton*)

The feed opening which is between the inner swinging gate and the outer frame swings downwards immediately the ram begins its descent. Fingers in the danger zone are pushed to safety. The fixed side guards prevent access to the trapping area except through the feed opening.

In the case of a device with an upward-moving member, rising vertically or practically vertically, an attachment of a minimum width of 9 in. should be fitted to the top edge, horizontally towards the trapping area. During the first 6-in. rise this should move outwards towards the operator through an arc of not less than 70 degrees.

Moreover, this moving member, before the trapping distance between tool and dies becomes less than 5 in., should rise so that the top edge of the attachment is not less than 5 ft. 6 in. With the safety device in this position, it is practically impossible for the operative to be trapped between tool and die.

There is no doubt that the large majority of the work which these presses are required to do can be carried on with these standing safeguards.

At the same time it must be remembered that the guarding of many heavy presses, and the components with which they have to deal, present problems at one time regarded as insuperable. The ever-present necessity for adequately protecting the operator, however, led to a rapid development in the design of automatic guards for large presses, and an excellent example is shown in Figs. 28 and 29.

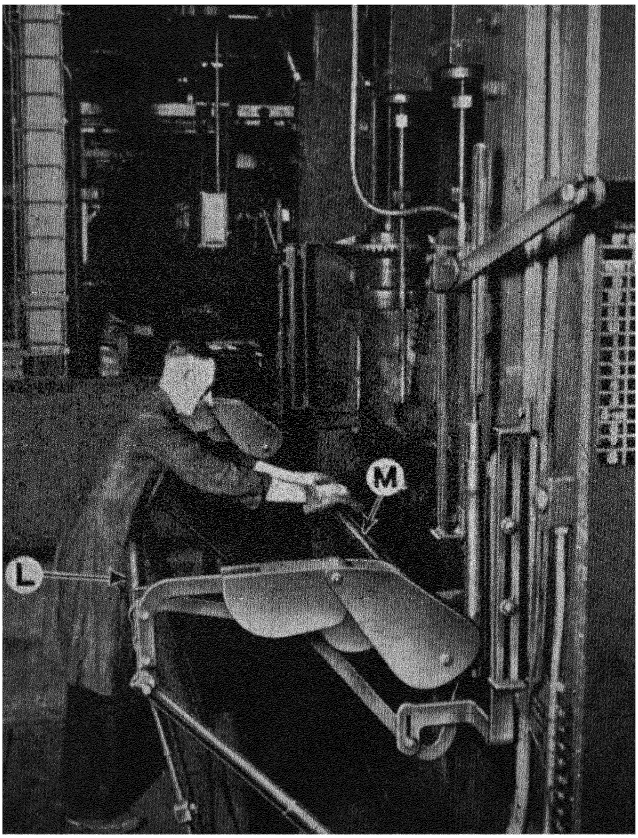


Fig. 28.—With the descent of the ram the outer safety bar moves outward

(*J. Broughton*)

The guard consists of two lazy-tong units, one fitted to each side of the press with the driving mechanism necessary for their operation. With the ram at the top of the stroke, the lazy-tong units are shut, and the safety bars close up to the press as shown in Fig. 29.

As the ram descends, the outer safety

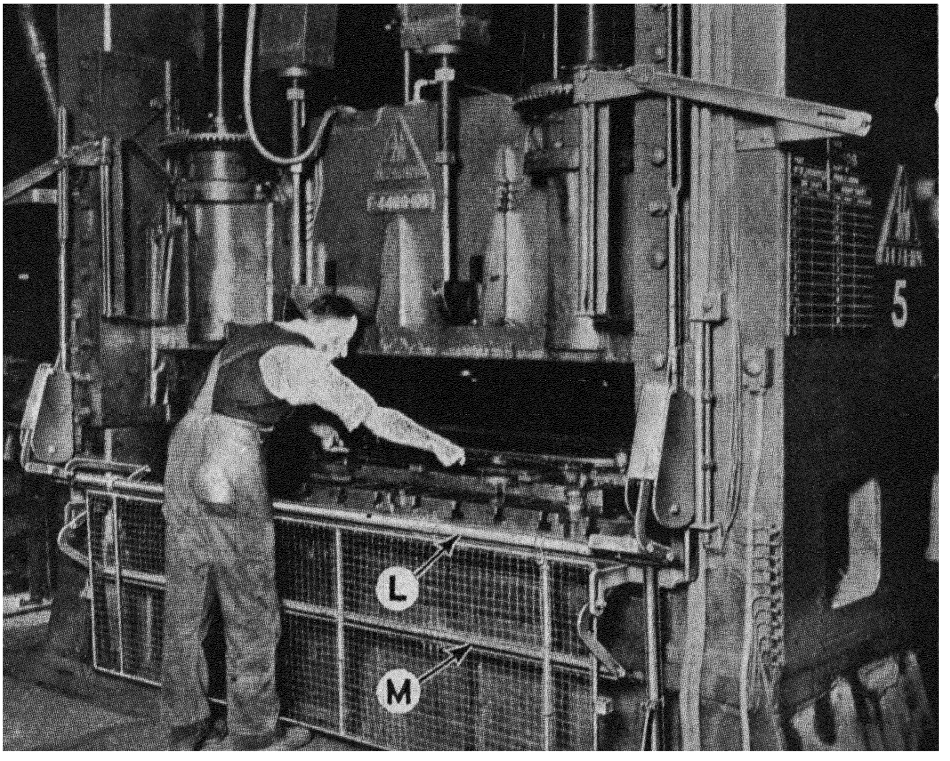
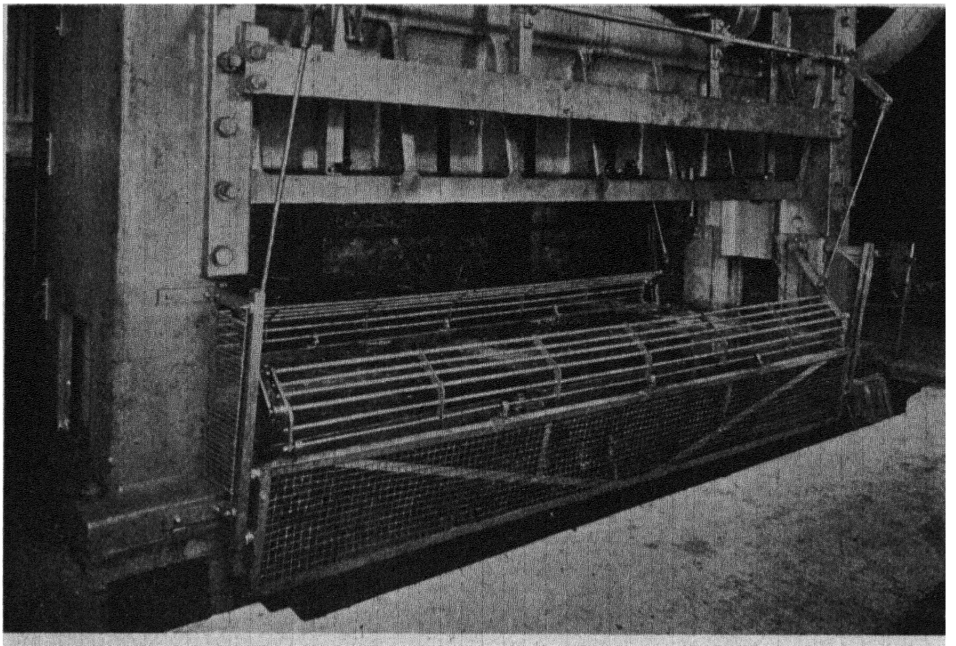


Fig. 29.—THE RAM IS AT THE TOP OF THE STROKE, AND THE SAFETY BARS ARE SEEN CLOSE UP TO THE PRESS (*J. Broughton*)

bar moves outward at an initially rapid rate, pushing away anything that may be in its path.

The provision of a secondary safety bar " M " ensures that in the event of a low die the operator will be prevented from overbalancing. In the closed position this bar lies in a vertical position behind the screen, as may be seen by referring to Fig. 29. As the guard moves outward, this bar revolves about its axis up to the height of the bar " L " (see Fig. 28). A suitable screen is attached to the bar " L " to prevent access from below the bar and also from the sides.

The whole problem of securing real safety when the use of fixed guards is prohibited by the nature of the operations, would be largely solved if by some means the descents of the ram other than those willed by the operator were eliminated. One means of securing this desirable state of affairs has been in use for some time—the positive stop in conjunction with a slipping member incorporated in the flywheel. If the adventitous stroke tends to occur, the press ram is prevented from descending and the flywheel energy is dissipated in the slipping member. But its use is not universal.



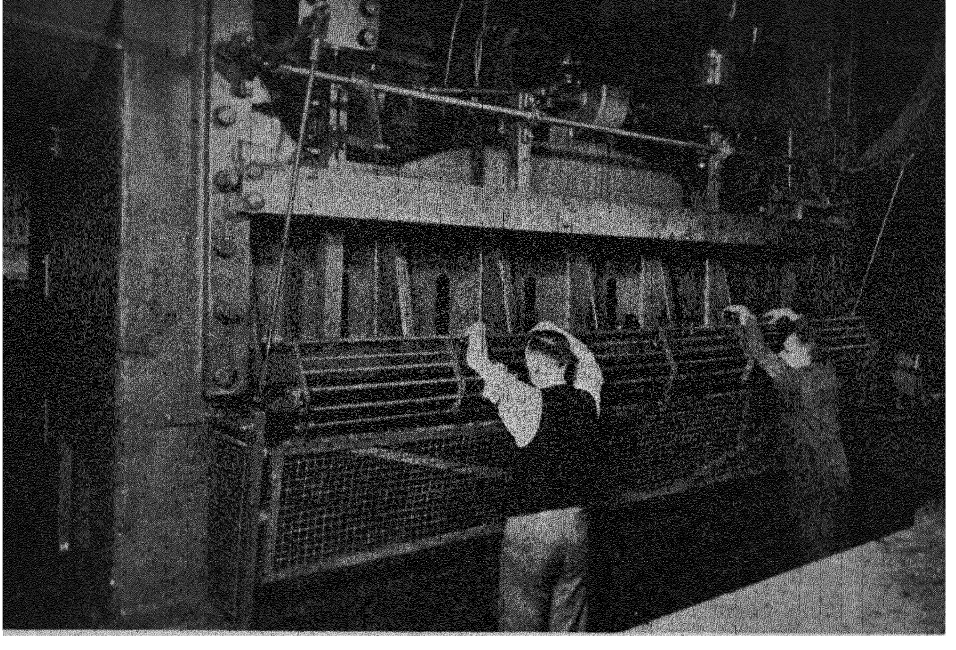


Fig. 30 AND *Fig.* 31 SHOW A " SAFETY LIFT " GUARD FITTED TO A 700-TON DOUBLE-CRANK PRESS

(*Press Guards Ltd.*)

The action of the guard is designed to move the operators from the danger area during the early part of the downstroke of the press.

Push-button Control

In a press actuated by push-button control, descent of the ram will not take place, provided the push buttons are suitably placed, until all the workers engaged on the machine are pressing a button and standing in a safe position to do so. The safety conferred is illusory, for it does not take into account the fact that it not infrequently happens that an extra worker is brought into the team to cope with a special job. Nor does it provide safety in the event of a repeat stroke, and the object of the push-button device has more than once been neutralised in practice by "scotching" by the operatives. There have been many accidents following this practice.

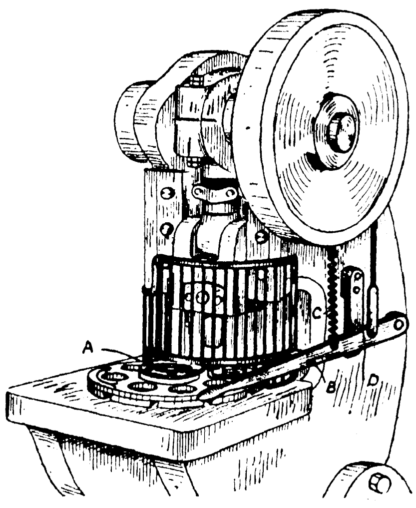


Fig. 32.—GUARD FOR DIAL-FEED OPERATION

This guard not only prevents access to the danger zone but obviates the risk of trapping between the lower edge of the guard and the recess in the turntable. The guard is mounted on a loose ring A fitted over the turntable axis so that if a finger becomes trapped between one of the turntable recesses and the left side of the guard its right side swings against clutch handle B, which is kept depressed by the pressure of tension spring C against latch D, forcing the clutch lever clear of the catch and allowing it to rise, thus disengaging the clutch and bringing the machine to a halt.

On the principle of the old axiom that prevention is better than cure, tools and dies should be designed with safety factors kept clearly in mind. Care should be taken that locating pins or slides are in such positions as not to be within easy reach of any person working at the press. But where this cannot be avoided and a dangerous trap occurs between the locating pin or slide and its corresponding register, then, in advance of the trap between the working surfaces of the tool and the die, secure local fencing should be provided. By a little careful thought in the beginning it is often possible to obviate the necessity for such local fencing by designing tool and die so that the locating pin or slide at no time leaves its corresponding register.

While local fencing may be a counsel of perfection, in actual practice its fitting might adversely affect the smooth-flow working of the press, owing to interference with the loading and unloading. In such cases great care must be taken to see that the trap occurring in respect to the locating pin or slide approximates closely to the trap occurring between the working surfaces of the tool and die. The normal guarding of the press is then adequate safeguard in itself. Accessible surfaces, other than the faces of the tool, die, and pressure plates, should not meet within 5 in.

Chapter IV

POWER-PRESS OPERATIONS

METALS may be worked in power presses in a wide variety of ways. Often it seems as if each new press operation is a problem in itself. It is possible, however, to assemble most press operations into several closely related groups. The relation in these groups and between groups is here based upon a comparison of the stresses and strains in the metal being worked.

In shearing operations the metal is stressed locally beyond its ultimate strength, causing a fracture. In most other press operations the metal is stressed locally or generally beyond its elastic limit in order to form it, but not up to its ultimate strength lest it break. Therefore, where the operation is severe, a wide range between the elastic limit and the ultimate strength is desirable. The question of hardening and increasing the resistance in cold working arises as a limiting factor, bringing in the matter of re-crystallisation in annealing for further operations. (See Fig. 1.)

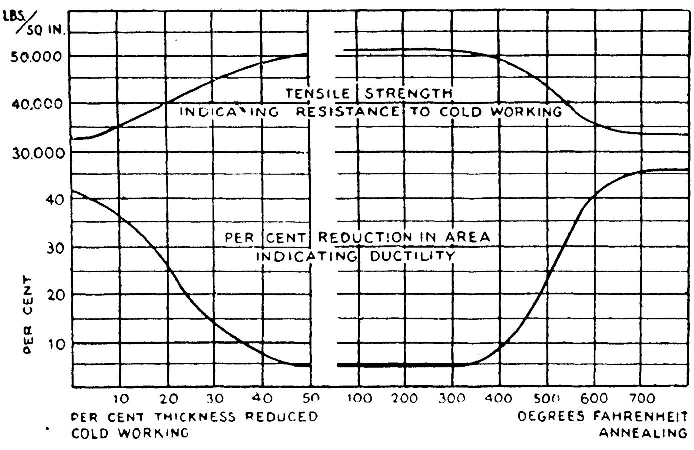


Fig. 1.—Increasing resistance and decreasing plasticity of copper by cold deformation and normalising again by annealing

Deformation

Metals and their alloys harden in definite crystalline patterns. The atoms in the individual crystal arrange themselves uniformly with planes of weakness or slip planes running through the crystal in different directions depending upon the pattern for that metal. In plastic deformation or cold working of a metal, "slippage" occurs along certain of these planes of weakness when the elastic limit is exceeded, but the atomic attraction between adjacent planes is such that a resistance to "slippage" builds up, causing the

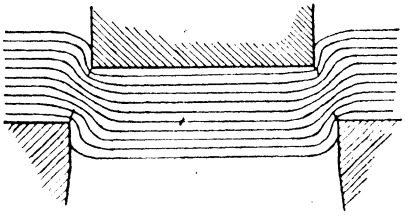


Fig. 2.—FRACTURES STARTING IN THE SEVERELY STRESSED METAL AT THE CUTTING EDGES

" slippage " to be continued in other planes and so on, with the result that fracture does not occur until the ultimate strength is reached at a much higher unit stress. The many crystals which go to make up a piece of metal are naturally not placed or oriented in the same way. Therefore, in the case of deformation of the whole piece, the " slippage " must spread along the slip planes of adjacent crystals, selecting a path as favourable to its progress as possible. The resulting irregularity accounts for the characteristic appearance of a fracture.

Strain Hardening

" Cold working " at normal atmospheric temperatures reduces the grain size in steels, copper, and brass, etc., or at least distorts and shatters the existing grains, and is accompanied as a rule by increased hardness and strength of resistance. Elevating the temperature to the annealing range causes recrystallisation and grain growth, returning the metal to a workable state. Metals such as zinc, lead, and tin which recrystallise near or below " room temperature " are not subject to this " strain hardening."

The four general headings under which the various press operations will be grouped are shearing, forming (largely bending), drawing, and squeezing. These are indicative of what is being done to the metal, and most press operations, judged by what happens in the metal, fall quite distinctly into one or another. Obviously some operations, such as combination-die blanking and drawing, contain elements belonging to two groups. A few, like bulging, are troublesome to place.

Most press operations are performed cold. Heating is expensive and handling hot work is usually slow. The application of heat is desirable in many cases, however, on account of shape, total pressure, intensity of local pressure, avoiding strain hardening and strains in the finished work (in steel and brass), etc.

Shearing

In shearing operations only, the metal is stressed to the point of fracture. As illustrated in Fig. 2, the metal is pinched between the cutting edges of the punch and die. The greatest strain is localised at the cutting edges and the punch progresses until fractures start in the surface metal at these points. Once started the fractures spread quickly, completing the separation. A sharp cutting edge localises the pressure better and causes fracture earlier than a dull edge. A clean break is obtained by having suitable clearance between the

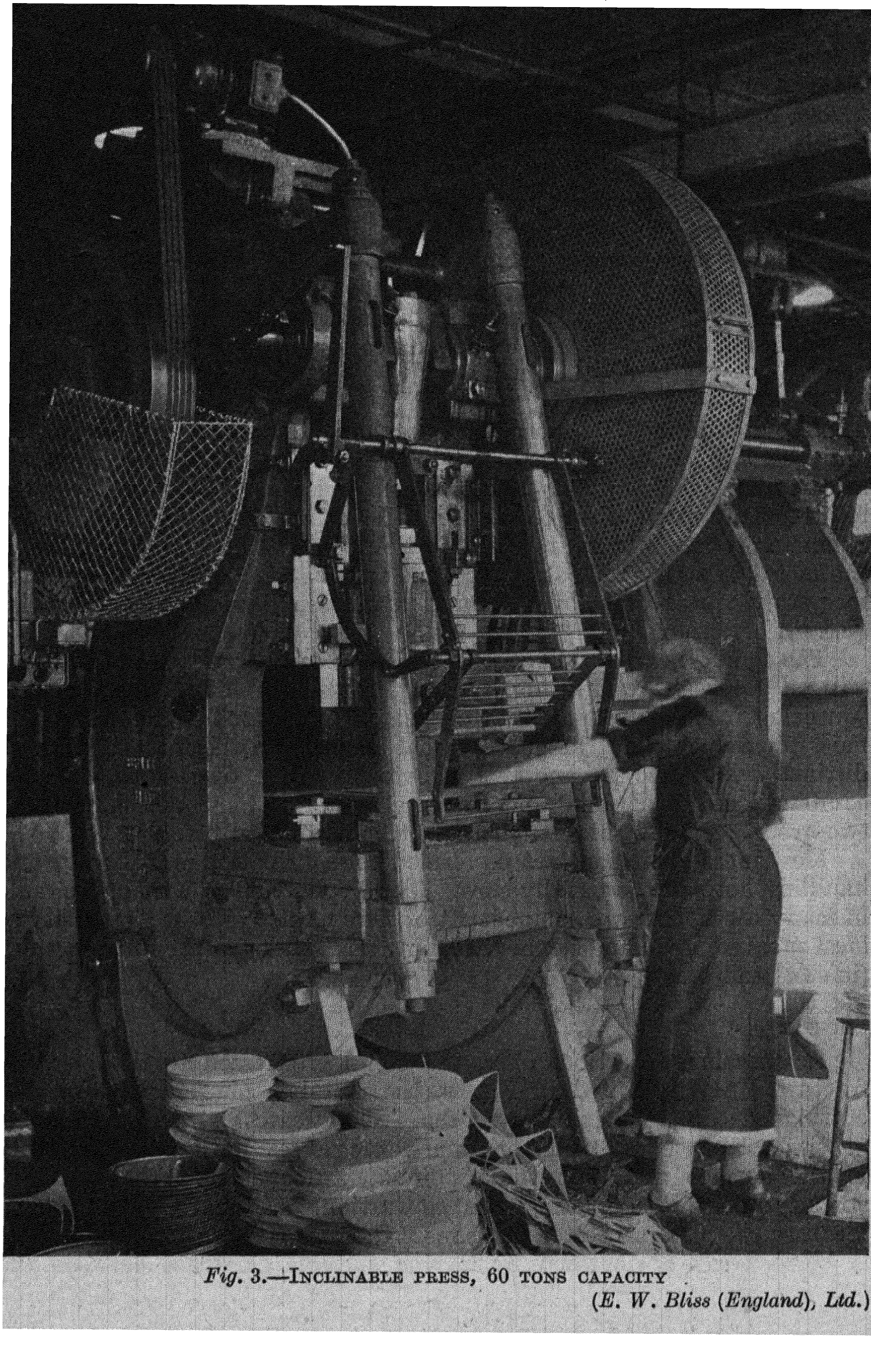


Fig. 3.—Inclinable press, 60 tons capacity

(*E. W. Bliss (England), Ltd.*)

punch and die uniformly all round. Hard metal requires less penetration to effect shearing than soft metal. Hard metal also requires less clearance for a clean cut than soft metal, but due to its hardness, it is possible to get away with more clearance than on soft metals. An old rule of thumb states that the clearance between punch and die all round should be about a tenth of the thickness of soft metal, varying to an eighth of the thickness of hard metal, and going as high as a quarter of the thickness on some perforating operations using very fine punches.

Various Operations

The operations quite obviously grouping themselves under the general head of shearing include blanking, punching, compound blanking and punching, follow-die punching and blanking, blanking and repunching, shearing (on one or two sides only of a shape), shaving, broaching, trimming, and hot punching. Combination dies include the functions of plain blanking and of drawing, the blanking punch serving also as blankholder for the drawing operation.

In plain blanking or cutting a desired shape out of strip, sheet, or scrap metal, the shape is ordinarily pushed through the die. Below the cutting edge the die is straight for a short distance and then opens out at a clearance angle of perhaps 2°. If it is straight for too great a distance, there may be a tendency to wear bell-mouthed at the top, permitting the uppermost of the blanks being pushed through to suck back on the face of the punch. Since the shape to be produced should be flat, the punch is ground flat and any shear angle is ground on the surface of the die. When the shape is to be held accurately to size, the die

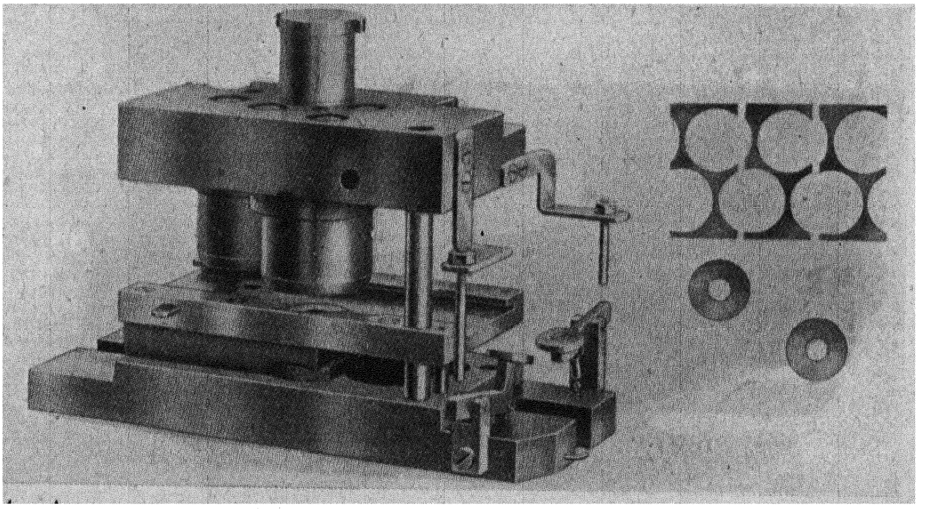


Fig. 4.—A COMBINATION TOOL AS USED IN AN INCLINABLE PRESS FOR BLANKING AND PIERCING WASHERS TWO AT A TIME IN ONE OPERATION

(*Taylor & Challen, Ltd.*)

is made to that size and the punch is smaller by the amount of the clearance. Fixed stripper plates about the punch are usually sufficient for this work. The shape or blank may be dropped into a box under the press, stacked in a curved stacker turning out and up from the underside of the bolster, or pushed out on edge on a straight stacker when the press is operated in or near the horizontal position. Most fine-cutting dies are made with substantial guide pins and bushings as a partial assurance of getting proper alignment in die setting and maintaining it in operation.

Stepping the Punches

In punching holes in a blank, sheet, or formed article, the metal sheared out is the scrap. Here the die should be flat and any shear required should be ground on the punch. Where a number of punches are used, shear may be applied by stepping the punches, that is, making

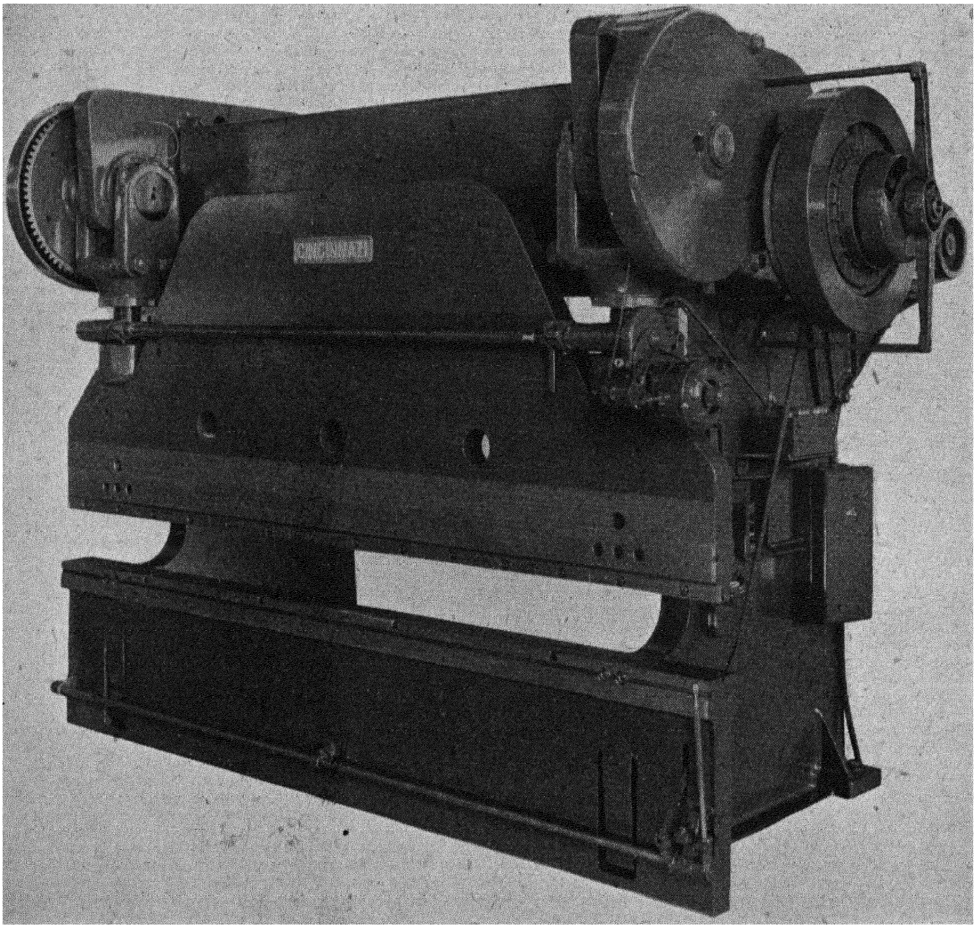


Fig. 5.—" CINCINNATI " PRESS BRAKE

some shorter than others by an amount equal to the distance the punch must penetrate into the metal to effect shearing. Where a large punch and several small punches are employed, particularly on comparatively thick metal, the large punch should enter first, so that crowding out of the metal due to its initial penetration will not deflect and possibly break the smaller punches. Where a hole must be accurate to size, that must be the size of the punch, and the die is larger by the amount of the clearance. Where delicate small-diameter punches are used, cutting half blanks, that is, punching at or very near the edge of the metal, should be avoided, due to deflecting the punches and causing them to chip or wear on the cutting edge of the die. Punches smaller in diameter than the thickness of the metal to be punched are usually considered impractical. They may sometimes be made to stand up by using exceptionally large clearances. Spring strippers are used to a considerable extent on punching operations to hold the work flat. Cam-actuated strippers are also used, particularly on perforating operations, to support the punches in some cases and to hold the stock down tight, reducing distortion due to the crowding between punches. The stripping load is reduced by keeping the punches parallel and well polished.

Compound Punching

Compound blanking and punching, or cutting a blank and cutting a part or parts out of it at the same time and in the same die, is the most accurate method of producing a shape with holes in it. The blank can never be pushed through the die, though in many cases the punchings may be. In other cases both the blank and the punched-out centre are returned to the surface of the die to be removed with the scrap. Where dies with spring stripping rings and spring centre knock-outs are used, the blank may sometimes be pushed back into the stock sufficiently to carry it out of the die. Inclined or inclinable presses are often used on compound die work to permit the blank and punchings to slide off to the back as the sheet and scrap are moved across from side to side. In these cases cross-bar knock-outs in the press slide and cam or crank-actuated knock-outs in the bed may be used to time the stripping actions. Then, as in producing stator laminations, the blank may be dropped back from the face of the punch while the centre slides off the face of the die under the scrap, often with the assistance of an air blast.

An Alternative Method

Follow-die punching and blanking is the alternative method of producing blanks with holes in them in one handling. It is usually faster than compound-die systems, but the product is inclined to run somewhat less uniform. In the first step the hole or holes will be punched, pushing the scrap through the die. In the second step the shape is blanked and

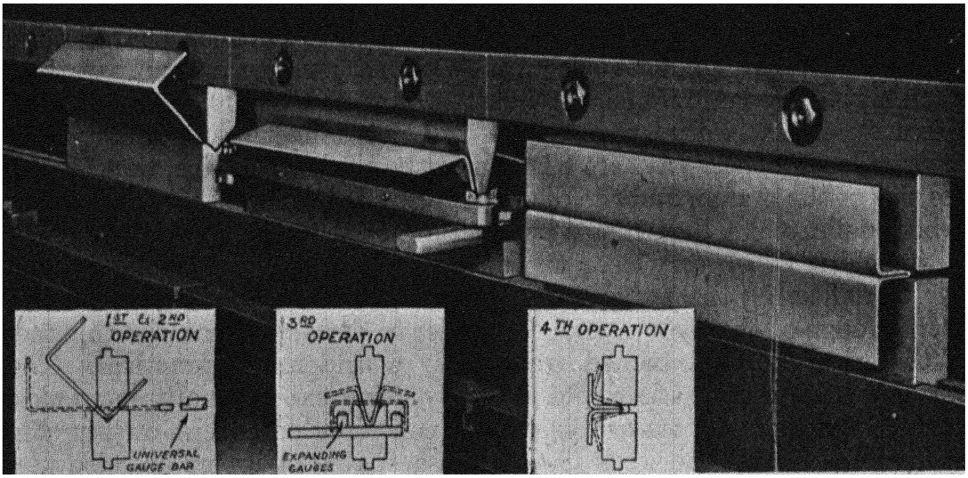


Fig. 6.—Typical sequence of operations as carried out on a "Cincinnati" press brake

pushed through the die. In this second step bullet-nosed pilots are provided in the face of the blanking punch, or better, beside it to enter the holes previously punched in the shape or punched particularly for the purpose in the scrap. These pilots correct any misalignment of the sheet so that the holes will be properly located in the blank. In roll feeding, the grip of the rolls must be relieved just before the pilots enter to permit this correction. Piloting in the scrap or in an intermediate idle position is usually best, so that fairly tight-fitting pilots can be used without danger of having a blank stick on the punch.

In the repunching method the outline of the shape is blanked in one operation. The piece is then located in a gauge or nest, and the narrow slots and holes are punched, relieving these delicate punches of considerable strain and separating them in upkeep from the heavier blanking die.

Saving Scrap

There is one method of blanking best described as shearing, in which, for example, one or two sides of a shape are cut at each stroke of the punch, the other sides of the shape having been produced in the previous stroke. This applies principally to such symmetrical shapes as "L" laminations for transformers. The object is to save the in-between scrap which would be lost in blanking the shape all round. Shearing dies usually have a much shorter life than blanking dies, due to the unbalanced loading and the tendency to move away from the side where the shearing is being done. Such dies require very heavy shoes and solid support from the die behind the punch (on the side where no shearing is being done) and above the cutting level.

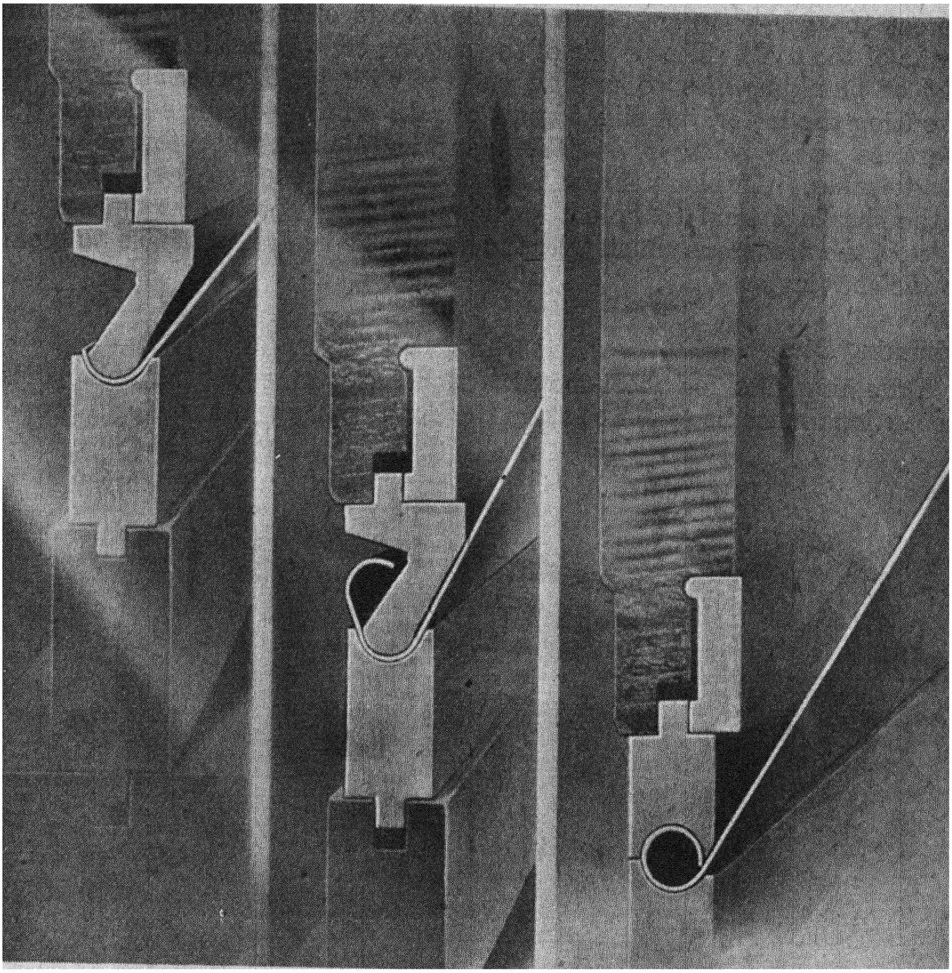


Fig. 7.—Illustrating the action of a typical press brake

Shaving Dies

Shaving the outside of a shape or broaching the inside of a hole to give a better finish than a sheared edge, to hold an accurate size or spacing or to produce fine teeth or knurling, etc., is more nearly related to machine-tool cutting operations than any other press work. The shaving die or broaching punch may be built with a single cutting edge to take off one shaving three- or four-thousandths of an inch thick (varying with the material, its thickness, finish desired, etc.). Or they may be built in several steps, taking off less and less of a shaving in each step down to one- or a half-thousandth in the last step for a fine finish. A burnishing or polishing steel with rounded edge and differing only slightly in size from the last shaving step may be added both to better the finish, and to

protect the last cutting edge from the effects of friction on the return stroke of the tool. The profile of the cutting edge varies in practice from that of blanking dies to milling cutters with good practice naturally favouring the latter. A slight angle of rake on the cutting edge, a slight clearance angle below it, and then considerable clearance for chips are all advisable. Air blasts through the steps may be used to clear the chips. If the shavings tend to hold together in a ring, notches in the cutting edges of the first steps which take the heaviest cuts are advisable to break up the shaving.

Trimming Dies

Trimming dies for sheet-metal articles are, in effect, shearing dies. Precautions must be taken to start the cutting edges in exact and proper

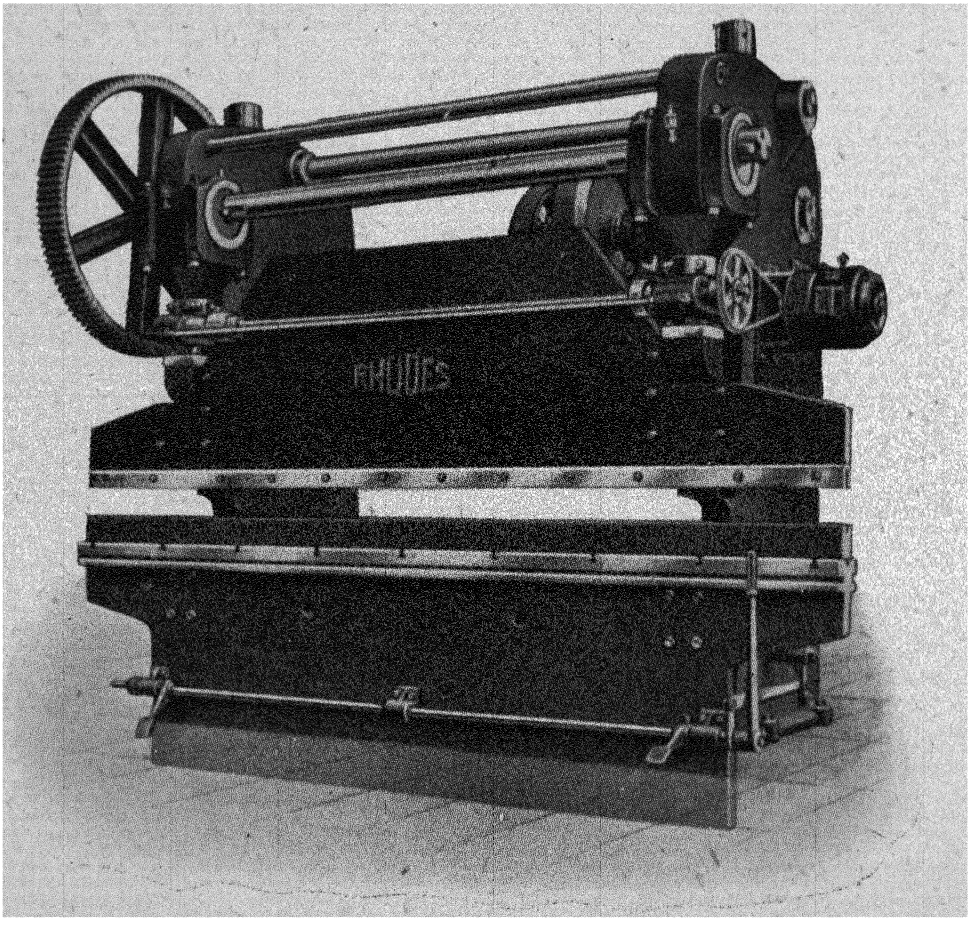


Fig. 8.—A BENDING PRESS—OR "BRAKE"—USED FOR FORMING BENDS IN THE MANUFACTURE OF AIRCRAFT, RAILWAY COACHES, AND SHEET-METAL FURNITURE

The use of the extended bed and beam is shown in Fig. 13.

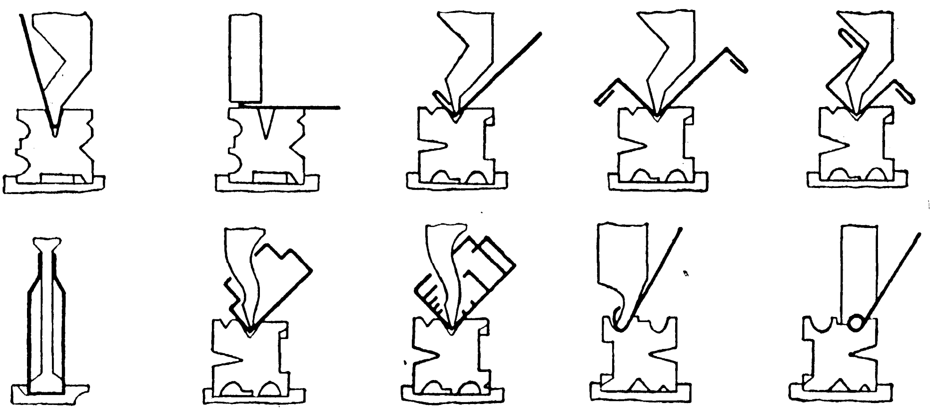


Fig. 9.—Various bending operations using Rhodes dies

relation to each other and to prevent their springing apart with resultant wear and burrs. Heavy shoes, large guide pins, backing plates, or ground spacing pins as in flat-edge trimmer dies, are wise precautions. In trimming the flange of drawn shells, and the like, ring scrap may be accumulated on the punch and broken up by three or four wedge-shaped scrap cutters around the punch.

Trimming dies for press forgings or drop forgings are usually rough affairs contending with considerable very hard scale and seldom having sharp edges or close clearances. A $\frac{1}{32}$ to $\frac{1}{16}$ in. is common clearance between such punches and dies. The dies usually have a large clearance angle, up to about 7°, and are ground flat on top. They are often made split in two pieces to permit compensating for wear and regrinding by moving the halves together. When forgings to be trimmed have a rounded or wide angle shape the punches are usually shaped to suit, so that they support close to the edge of the flash in trimming. Where the forging has a steep side for forging draft, the forging itself will support the flash amply and the punch has only to push it through.

In punching holes through hot steel the punch usually has a rounded edge and pinches the metal off. Where the metal is thick compared to the punch diameter, it is possible to so taper the punch nose that it will force out much of the hole scrap into the side walls. Only a small scrap slug is then pushed through and pinched off, as in pick-eye forging.

Forming

Forming is a rather miscellaneous classification. Its limits are much less sharply defined than are those of the other three groups. Bending, stressing the metal in tension, and compression at each side of its neutral axis (usually very locally), is the chief characteristic of most of the operations grouped here. Clearly it is much less severe in most cases than

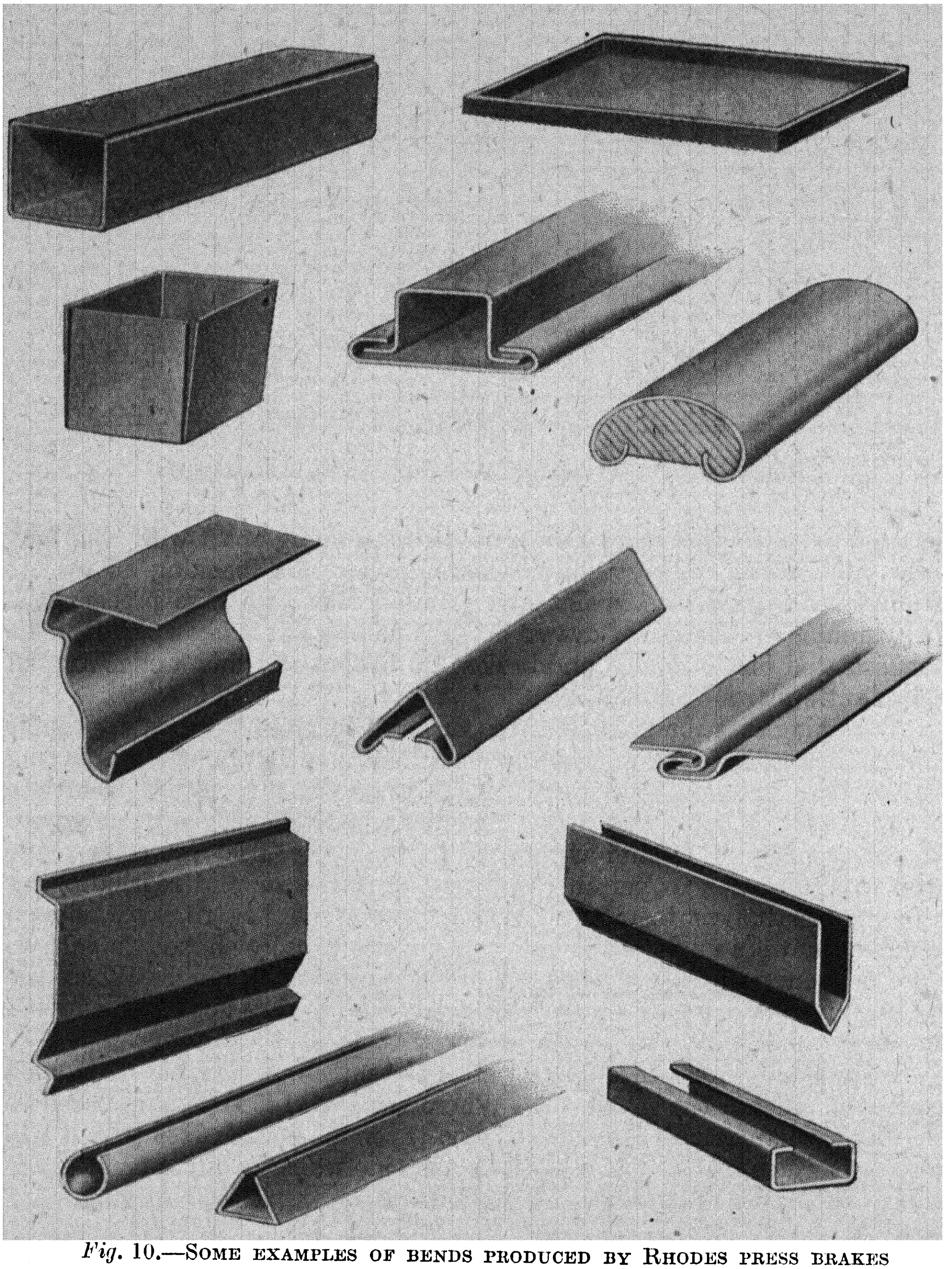


Fig. 10.—Some examples of bends produced by Rhodes press brakes

drawing, in which a large part of the metal is rearranged with bending merely incidental; and coining, in which the whole body of the metal may be worked.

Plain bending dies, making one bend, two balanced bends, or various

TABLE I.—ALUMINIUM SHEET AND PLATE
TYPICAL BEND RADII FOR 90° AND 100° COLD BENDS

NA Alloy Grade and Temper	*Approximate Thickness in S.W.G. and Inches*											
	27 ·016		21 ·032		16 ·064		10 $\frac{1}{8}$		6 $\frac{3}{16}$		3 $\frac{1}{4}$	
	90° *Bend*	180° *Bend*	90° *Bend*	180° *Bend*	90° *Bend*	180° *Bend*	90° *Bend*	180° *Bend*	90° *Bend*	180° *Bend*	90° *Bend*	180° *Bend*
2SO	0	0	0	0	0	0	0	0	0	0	0	0
2S¼H	0	0	0	0	0	0	0	0	A	A	A	A
2S½H	0	0	0	0	0	0	0	0	A	A	A	B
2SH	A	A	B	B	C	C	D	D	E	E	E	F
3SO	0	0	0	0	0	0	0	0	0	0	0	0
3S¼H	0	0	0	0	0	0	0	0	A	A	A	B
3S½H	0	0	0	0	0	0	A	A	A	A	B	B
3SH	B	B	C	C	D	E	E	F	F	G	G	H
4SO	0	0	0	0	0	0	0	0	A	A	A	A
4S¼H	0	0	0	0	A	B	B	C	C	D	D	E
4S½H	A	A	B	B	C	D	D	E	E	F	E	G
4SH	D	D	E	E	F	F	G	G	G	H	H	K
57SO	0	0	0	0	0	0	0	0	0	0	0	0
57S¼H	0	0	0	0	0	A	A	A	A	B	B	C
57S½H	0	0	0	A	A	B	B	C	C	D	D	E
57SH	B	C	C	D	D	E	E	F	F	G	G	H
17SO and Alclad 23SO	0	0	0	0	0	A	0	A	A	B	B	C
17ST and Alclad 23ST	C	C	D	D	E	E	F	F	G	G	G	H
17S and Alclad 23S as quenched	A	A	A	B	B	B	B	C	C	D	D	E
Alclad 21SO	0	0	0	0	0	A	0	A	A	B	B	C
Alclad 21ST	A	A	A	B	B	B	B	C	C	D	D	E
Alclad 21SW	D	D	E	E	F	F	G	G	G	H	H	H
51SO	0	0	0	0	0	0	0	0	0	0	0	0
51SW	A	A	B	B	C	C	D	D	E	E	E	F
51ST	E	E	F	F	F	G	G	G	H	K	K	K

0 = 0 radius　　B = $\frac{1}{2}$t to $1\frac{1}{2}$t　　D = $1\frac{1}{2}$t to 3t　　F = 3t to 5t　　H = 5t to 7t
A = 0 to 1t　　C = 1t to 2t　　E = 2t to 4t　　G = 4t to 6t.　　K = 6t to 10t
t—thickness of sheet

This table gives the approximate bend radii required for sheet. It is intended only as a guide in the selection of a suitable alloy or proper forming radius. Since the minimum bend radius depends on the nature of the forming operation, the type of equipment and the design and condition of the tools, the final choice of alloy and temper or radius should be based on actual trial under the proposed operating conditions.

Smooth, clean, well-lubricated tools should be used, and for short radii, sharp corners and burrs should be removed from the edges of the sheet near the bend line. In general, somewhat smaller radii can be used when the axis of the bend is at right angles to the direction of rolling when parallel to it.

(*By courtesy of the Northern Aluminium Company, Limited.*)

combinations, are infinite in variety. Many bending dies incorporate spring-pads or spring-pins to prevent the metal from creeping one way or another, and become a species of double-action die. Often bending dies include wedge actions, to get horizontal motions for undertucking, etc. The wedges are frequently in the form of substantial pins flattened or shaped-off on one side to combine the function of pilot and wedge, with the advantage that the nose of the pin enters the die before the wedge action takes place, and serves to back up the thrust and prevent the die from creeping.

Bending

In making a right-angle bend in elastic material *it is often necessary to bend more than 90° to allow for spring back.* In forming a channel or otherwise bending by pushing past a corner, the legs bent up may be long, but it is usually unnecessary to pass the corner by more than two or three times the corner radius.

The making of bushings and the like is a development of the U-ing die. The bushing may be made progressively in one or several presses in a series of simple dies, or in some cases it may be made in one operation in a special die or press with a floating mandrel and wedge-actuated side pieces.

Corrugation

Forming single corrugations across a sheet is plain bending. Closed ends bring the corrugation into the class of shallow rectangular drawing. A number of closed-end corrugations formed together necessitates considerable stretching and pulling-in, making the operation quite severe.

Forming dies for letters, panels, and shallow shapes, partake of the characteristics of drawing, and are best treated as drawing dies where possible. Forming dies which come together solidly, pinching the metal being formed, are responsible for more broken presses than any other press operation. Bending around a shape is a light press operation, whereas coining around that shape, even though the die is properly relieved, requires the heaviest type of press built. A double blank in such a die is certain to break something, and inaccurate die setting is also dangerous.

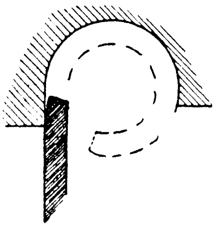


Fig. 11.—In curling the edge of a kettle or reflector the direction in which the edge was trimmed is important

Curling, wiring, or false-wiring (Fig. 11) may include some compressive or tensile stress about the edge, but is largely a bending operation. The important point is to have the smooth side, not the burr side, of the sheared edge sliding against the die in making the curl. A cylindrical shape is much easier to curl than a straight shape, particularly in a small curl, due to the tendency of a straight piece

TABLE 11.—PRESSURES REQUIRED FOR BENDING ANGLES

WIDTH OF VEE IN BOTTOM DIE (INCHES)

Thickness. Gauge	Thickness. In.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$
20	0·0375	3·12	**2·25**	1·68	1·43	1·10	—	—	—	—	—	—	—
18	0·0500	5·31	4·00	**3·00**	2·47	2·22	1·74	1·28	—	—	—	—	—
16	0·0620	9·59	7·08	5·55	4·50	**3·75**	2·78	2·18	1·77	1·47	—	—	—
14	0·0780	—	11·90	9·23	7·58	6·25	**4·68**	3·47	2·98	2·45	2·11	1·84	—
12	0·1090	—	—	—	16·70	13·10	9·69	8·02	**6·54**	5·56	4·58	4·06	3·20
11	0·1250	—	—	—	—	19·20	14·20	11·10	8·99	**7·50**	6·34	5·54	4·35
10	0·1410	—	—	—	—	—	18·60	14·50	11·90	9·94	**8·46**	7·29	5·77
$\frac{3}{16}$	0·1875	—	—	—	—	—	—	27·40	23·10	19·30	16·40	14·30	**11·20**
$\frac{1}{4}$	0·2500	—	—	—	—	—	—	—	—	39·40	33·30	29·50	22·70
$\frac{5}{16}$	0·3125	—	—	—	—	—	—	—	—	—	—	50·40	39·80
$\frac{3}{8}$	0·3750	—	—	—	—	—	—	—	—	—	—	—	61·60

Thickness Gauge	Thickness In.	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	6	7	8	10	12	—
11	0·1250	2·94	—	—	—	—	—	—	—	—	—	—	—
10	0·1410	3·95	—	—	—	—	—	—	—	—	—	—	—
$\frac{3}{16}$	0·1875	7·50	5·70	4·40	—	—	—	—	—	—	—	—	—
$\frac{1}{4}$	0·2500	**15·40**	11·40	9·00	7·35	6·06	—	—	—	—	—	—	—
$\frac{5}{16}$	0·3125	27·00	**19·70**	15·30	12·70	10·50	7·74	—	—	—	—	—	—
$\frac{3}{8}$	0·3750	42·30	30·90	**24·00**	19·60	16·30	12·30	9·46	—	—	—	—	—
$\frac{7}{16}$	0·4375	61·70	45·80	35·40	**28·60**	24·40	17·30	14·80	11·20	—	—	—	—
$\frac{1}{2}$	0·5000	85·20	63·60	48·80	39·70	**33·30**	24·60	19·40	15·90	13·10	—	—	—
$\frac{5}{8}$	0·6250	—	110·00	86·20	70·00	58·30	**43·10**	33·30	27·40	23·30	16·90	—	—
$\frac{3}{4}$	0·7500	—	—	138·00	110·00	93·00	68·70	**53·50**	43·60	36·50	27·10	21·00	—
$\frac{7}{8}$	0·8750	—	—	—	165·00	137·00	104·00	80·70	**64·60**	52·90	39·70	31·60	—
1	1·0000	—	—	—	—	197·00	143·00	113·00	91·20	**76·20**	56·30	44·20	—

N.B.—The ton pressures in bold type are exerted when using vee-shaped dies having openings eight times the thickness of the material being bent. Such dies are generally used for right-angle bending.

(*Joseph Rhodes & Sons, Ltd.*)

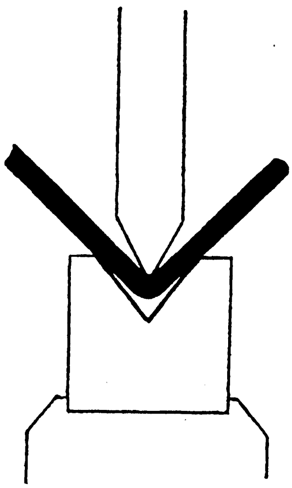


Fig. 12.—VEE DIE

to wave away from the starting side of the die and jam, instead of curling. Using rolls instead of dies for curling is of course a lighter but slower method.

Bulging and Beading

Bulging (and beading, which is similar but on a small scale) includes considerable stretching and in some cases may be related to drawing. It seems best classified with forming, however. The choice for bulging operations is between relatively slow rolls in spinning lathes, rather expensive wedge-operated mechanical bulging dies, rubber bulging dies which require a split holder and give limited service, or water bulging dies which are capable of producing some unusual shapes.

Necking-in operations, usually considered with beading, are quite the reverse in action. They are usually performed with rolls or mechanically operated contracting die steels which crowd the metal together.

Drawing

In drawing operations, metal is caused to flow from the flat sheet or a previously drawn shape into other shapes. The word flow is used advisedly, for while an approximately uniform thickness is maintained, the metal is stretched and squeezed to a very great extent in obtaining the desired shape. Squares scribed on the surface of a blank may be altered in a single drawing operation to distorted diamond shapes, or to rectangles increased in length and thickness up to 20 per cent, or even more and decreased in width by around 30 per cent. This distortion is, of course, increased in further redrawing, so that the prime importance of ductility in this class of work is obvious.

Stresses

The force of a punch, for example, pulling a flat sheet into a round shell, primarily causes a tensile stress in the metal, the direction of this stress being radial from the punch and spreading toward the outside edge of the blank. As the blank is drawn down, its circumference is continually being reduced. The metal in any ring, toward the outer circumference, is continually being squeezed as it is pulled in toward the centre. This squeezing ceases when the metal goes over the die radius into the side wall of the shell.

The radial tensile stress in the metal causes a resultant compressive stress in the flat portion of blank being held under the blank holder. This compressive stress often materially exceeds the tensile stress. It

is the compressive stress which causes the tendency to wrinkle and require either rigidity or considerable pressure on the blankholder.

Range of Ductility

The combination of the tensile loading and resultant compressive loading in the metal characterises all drawing operations. The elastic limit of the material must be exceeded to start it moving, but its ultimate strength must not be exceded, or a crack or tear will result. Accordingly, metal having a low elastic limit compared with its ultimate strength (a wide range between the two) is desirable. In steel this ductility is best in the lower carbon contents.

In the metal, drawing is accomplished by intra-crystalline " slippage." Cold working results in gradual distortion of the crystals, or strain hardening, varying with the material and usually requiring annealing to correct it.

Cupping, shallow drawing, deep drawing, redrawing, and ironing are progressively related with distinctive characteristics. Reverse drawing is a modification of redrawing. Ironing or thinning the side walls of a drawn shell seems in a class with swaging, but shows the initial tensile loading in the metal and resultant compressive stress in the zone of deformation which characterises drawing. It is most nearly related to wire drawing. It is usually performed with slight redrawing to enter the punch easily.

Stamping operations which do not pinch or squeeze the metal but merely form it up into letters, designs, corrugations, or beads are also related to drawing. Dies for such work are best arranged as shallow drawing dies which do not strike bottom.

Cylindrical Shapes

Drawing cylindrical shapes stresses the metal severely but uniformly all round the periphery of the shell. Rectangular shapes require little more than bending the metal over the straightedges, with

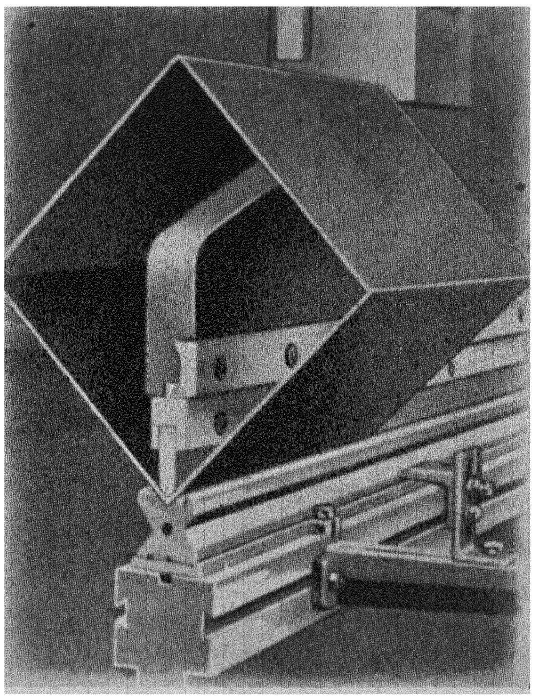


Fig. 13.—An extension of the bed and beam permits the shaping of rectangular boxes

drawing only at the corner radii. This corner drawing is comparatively easier than it would be in a cylindrical shell of similar radius and height, as the compressive stress set up in the metal under the blankholder about the corner forces much of the surplus out into the unstrained material going into the side walls. The blank-holding pressure and drawing radius for cylindrical shapes is uniform all the way round, but on rectangular shells it is frequently necessary to pinch very much harder at the corners than along the sides and to modify the drawing radius at those points.

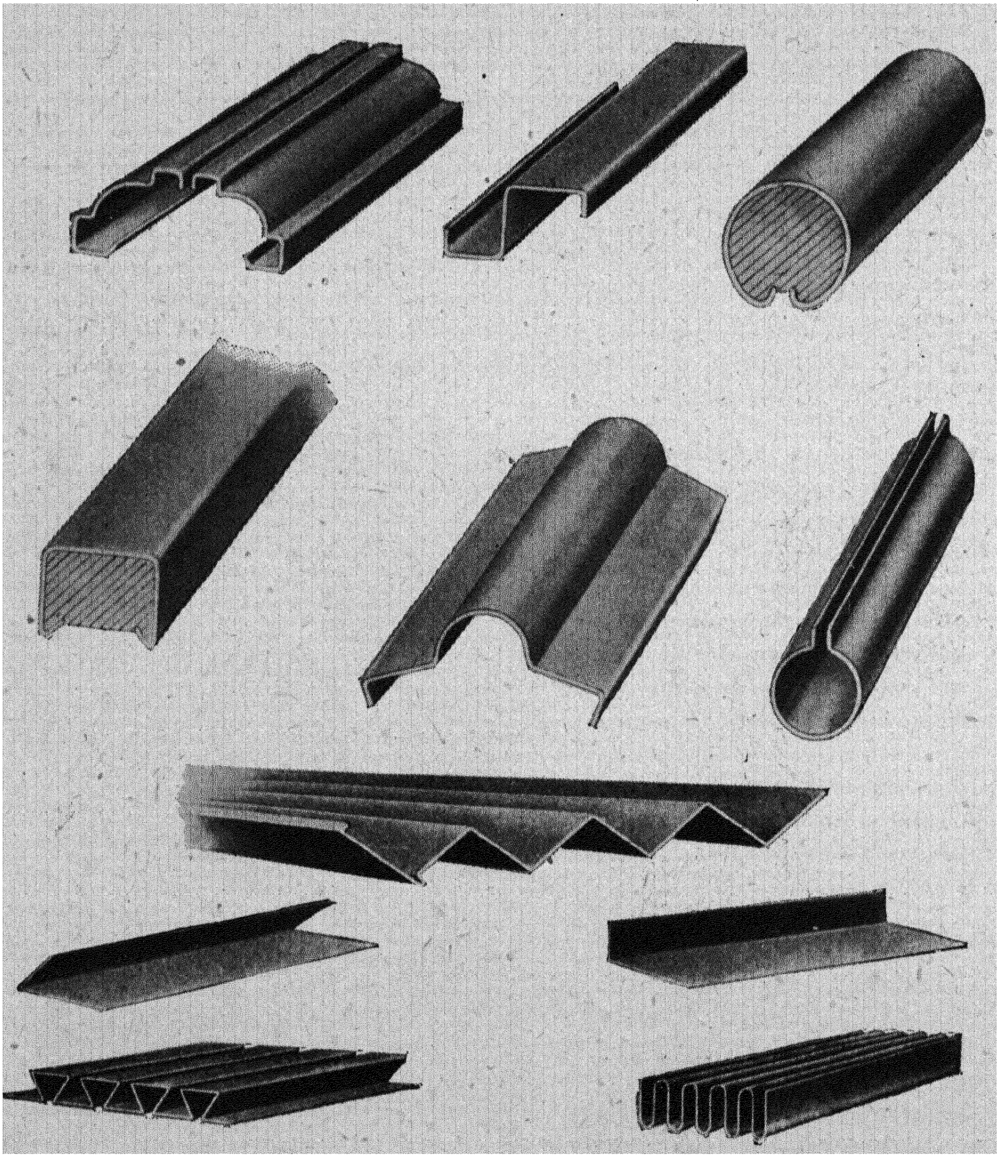


Fig. 14.—CORRUGATED WORK PRODUCED BY A "RHODES" PRESS BRAKE

Some low shells, drums, and covers of relatively large diameter and relatively thick metal may be drawn without holding the blank down in any way. This is true where wrinkles around the periphery of the blank, due to the circumferential compressive stress, can be prevented by gradually but continuously working the edge up and in as the drawing progresses. The draw corner of the die is usually developed with a parabolic profile for this work.

Dwelling on the Blank

Slightly deeper shells, proportionately, may be drawn with a very brief dwell of a blankholder. Advantage of this has been taken in double-action crank presses, a fast type of machine with punch slide and blank-holding slide both crank actuated. The two slides are so timed that the outer slide cuts the blank toward the lower end of its stroke and dwells slightly on the blank as it passes across bottom centre. During this period the inner slide does the drawing, acting at its greatest velocity (about mid-stroke), and carries the cup on well down below the die. These cutting and cupping presses used for metal buttons, bullet cups, etc., operate more rapidly than cam presses of similar size.

Double-action Dies

Most other drawing work requires double-action dies, in which the blank is held more or less tightly for the duration of the draw. The machines used may be single-action presses, fitted with rubber bumpers (for small work), deep spring pressure attachments or air cushions (which give easy regulation) in the bed of the press to supply the necessary holding pressure through pins located in the bolster. Or they may be the regular double-action presses having one crank-actuated slide for drawing and another slide timed for holding the blank and actuated either by cams on the crankshaft or by toggle mechanisms, which take the holding load through the frame.

The shallowest double-action work is represented by automobile body panels. Very little drawing is involved, but the shape is so shallow that, unless the blank is pinched well about the edges and stretched beyond the elastic limit of the metal, it tends to spring back towards the flat when released. To aid in gripping the edge of such a blank, it is often desirable to retard the flow of the metal by setting a draw bead or moulding into the blank-holding surface with a corresponding depression in the opposing surface of the die.

The Limit of Depth

The limiting depth of the first draw in deep drawing work is difficult to define, as it depends upon material and its quality, draw radius,

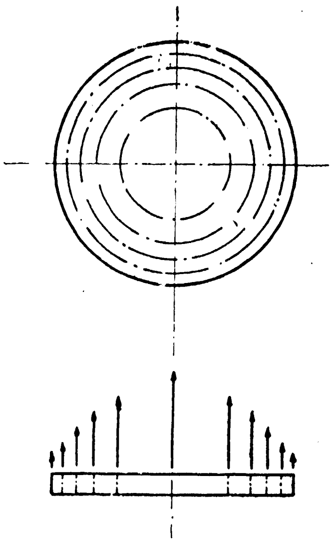


Fig. 15.—Resistance to side expansion causing a pyramiding of squeezing pressure in thin metal

bottom radius, relative thickness of material, permissible wall thickening, etc. For general purposes the greatest depth is sometimes placed at 45 to 65 per cent. of the shell diameter for round work and at four to six times the corner radius for rectangular shells.

In redrawing the shell to greater depths, the diameter is reduced by smaller amounts in each step. In double-action redrawing with a blankholder, the successive reductions may run up to 25 per cent., 20 per cent., 16 per cent., 13 per cent., 10 per cent., etc. This arrangement is modified by the relative thickness of the stock and the frequency of annealing. Single-action redrawing without a blankholder necessitates smaller steps, and depends upon the shape of the dies and punches. The steps may be for example 19 per cent., 15 per cent., 12 per cent., 10 per cent., etc. Reverse redrawing, turning the shell inside out in reducing its diameter, appears to have some advantage over the more common method, due perhaps to the fact that the metal of the shell wall is flexed only in one direction instead of being bent first one way and then the other.

Squeezing

The squeezing group of operations obviously work the metal in compression, although tensile stresses are set up also. Thus consider the disc in Fig. 15, divided up into five equal areas, as being in compression over its entire area. The central area, which may require only 20 or 30 tons per square inch to move it when free, must expand in diameter as squeezing progresses, and to do so must stretch all the rings in tension about it. This clearly causes pyramiding of pressure from the compressive strength of the material at the outside, to something very much higher at the centre. The pyramiding effect is emphasised by decreasing thickness and increasing area, whatever the shape. It has caused the failure of many cold swaging jobs by overstressing the die steels and therefore must be considered. The rugged knuckle-joint-type presses are used for most squeezing operations. The principal exceptions are press forging and extrusion.

Squeezing operations, and particularly the squeezing of steel, are practically the severest of all press operations. They may be divided into four general classifications according to severity.

Malleable Castings

Usually the least severe comparatively is mere sizing, flattening, or surfacing of parts of forgings, or castings like those illustrated, accompanied by very little reduction of thickness and no restriction on the movement of the metal to the sides. The bosses, bevels, flats, etc., on many drop forgings and malleable castings, particularly in the motor trade, are being squeezed accurately and smoothly to size (cold) to save milling or grinding operations. Ordinary tolerances for this work are closer than the milling tolerances used to be. When extremely close tolerances are required, within less than a thousandth, for example, it is desirable to arrange substantial size blocks to take half or two-thirds of the total load. These take up uniformly the bearing films and any slight deflection of the bed and bolster, and minimise the error due to variation in thickness, hardness, and area of the rough forging or casting.

The usual squeezing allowance in such work is $\frac{1}{32}$ or in some cases $\frac{1}{16}$ in. More may sometimes be used, but usually at the expense of a greater finish tolerance. Presses may be selected for this service on a basis as low as 60 to 80 tons per square inch, although 100 is more often used in the motor trade for reserve capacity. The lower figures should not be used where the thickness of the work is less than say half its average diameter, where it is confined all round the sides, where it is reduced more than a few per cent., or where its shape is changed materially.

The presses for sizing flat surfaces, especially for parts which do not require careful location in the dies, may be fed with slide feeds and magazine feeds to further speed up production.

Cold Forging

The second squeezing group in order of severity includes swaging, cold forging, or upsetting, in which a blank is squeezed down into an appreci-

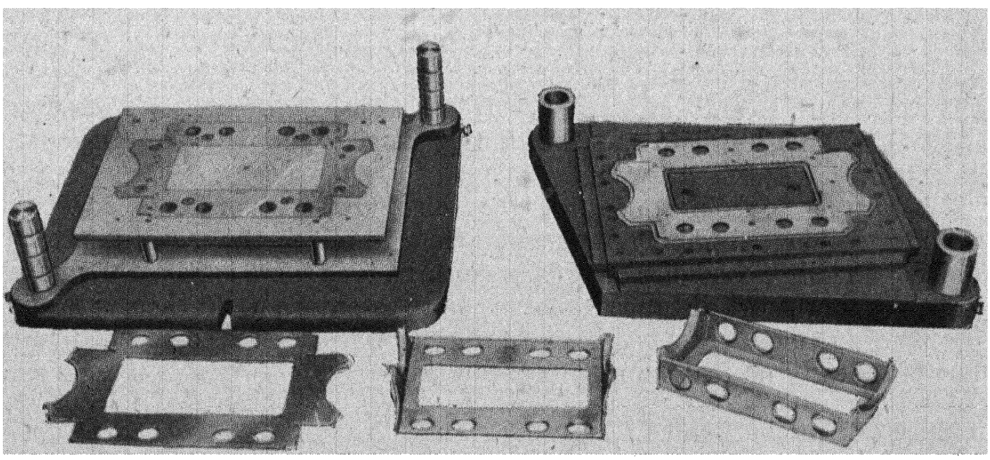


Fig. 16.—THE THREE STAGES IN THE PRODUCTION OF THIS COMPONENT FROM THE UPPER AND LOWER DIES SHOWN

ably different shape. An important consideration characterising the group is, again, considerable free-flow relief all round. As many of the blanks are comparatively thin, the pyramiding of pressure begins to require frequent attention.

Many small parts for sewing machines, adding machines, speedometers, etc., fall into this class of work, and there are usually three operations in making the pieces. The first is cutting a blank of suitable shape as thick as, or thicker than, the thickest part of the desired part. The remainder is then squeezed down possibly to half its original thickness, being free, however, to flow out to the sides. Finally, the squeezed portion is trimmed or shaved to get rid of ragged edges and obtain the final shape desired. In this manner are produced small gears with cams or single teeth on the sides, small levers with hubs on them, etc. Rivets for assembly jobs are squeezed out of the metal in a similar manner.

Press Forging

Another group closely allied to the second, except that the metal is squeezed into shape hot and squeezed into more intricate shapes, is press forging. Steel, forging brass, some copper, bronze, duralumin, etc., are forged in quantity production in substantial and usually fast tie-rod frame machines with eccentric-type shafts. Press forgings are usually characterised by good finish and closeness to size.

In steel particularly, a number of operations are frequently performed on the same piece, passing it from the furnace to two or three dies in the same press, or to several presses in quick succession. Some equipments doing this sort of work produce as many as twenty forgings per minute, interrupted occasionally by brief rest periods. There is a man at each operation with chutes conveniently arranged to deliver the hot pieces, and the whole line must keep up all the time.

Press-forged brass parts are usually adapted either by the shape of the piece or the shape of the slug used, to forging in a single stroke. The commonest mixture is around 59 per cent. copper, 39 per cent. zinc, and 2 per cent. lead forged around 1,300° or 1,400° Fahrenheit. Free-flow shape, good flash-relief, and uniformity in size and heat of slugs are desirable.

Returning to cold squeezing, the third group in order of severity includes coining, stamping, and embossing, in which the metal is pretty well confined in closed dies or thin sections, so that there is no relief, and is forced to flow short distances (short is quite essential) to fill the shape and profile of the dies. Steel comes into this classification for some stamping, but practically no real coining or embossing.

Choice of Knuckle-joint Presses

Government coinage, medals, some emblems and some silverware, in all of which the cross section of the finished piece varies in thickness,

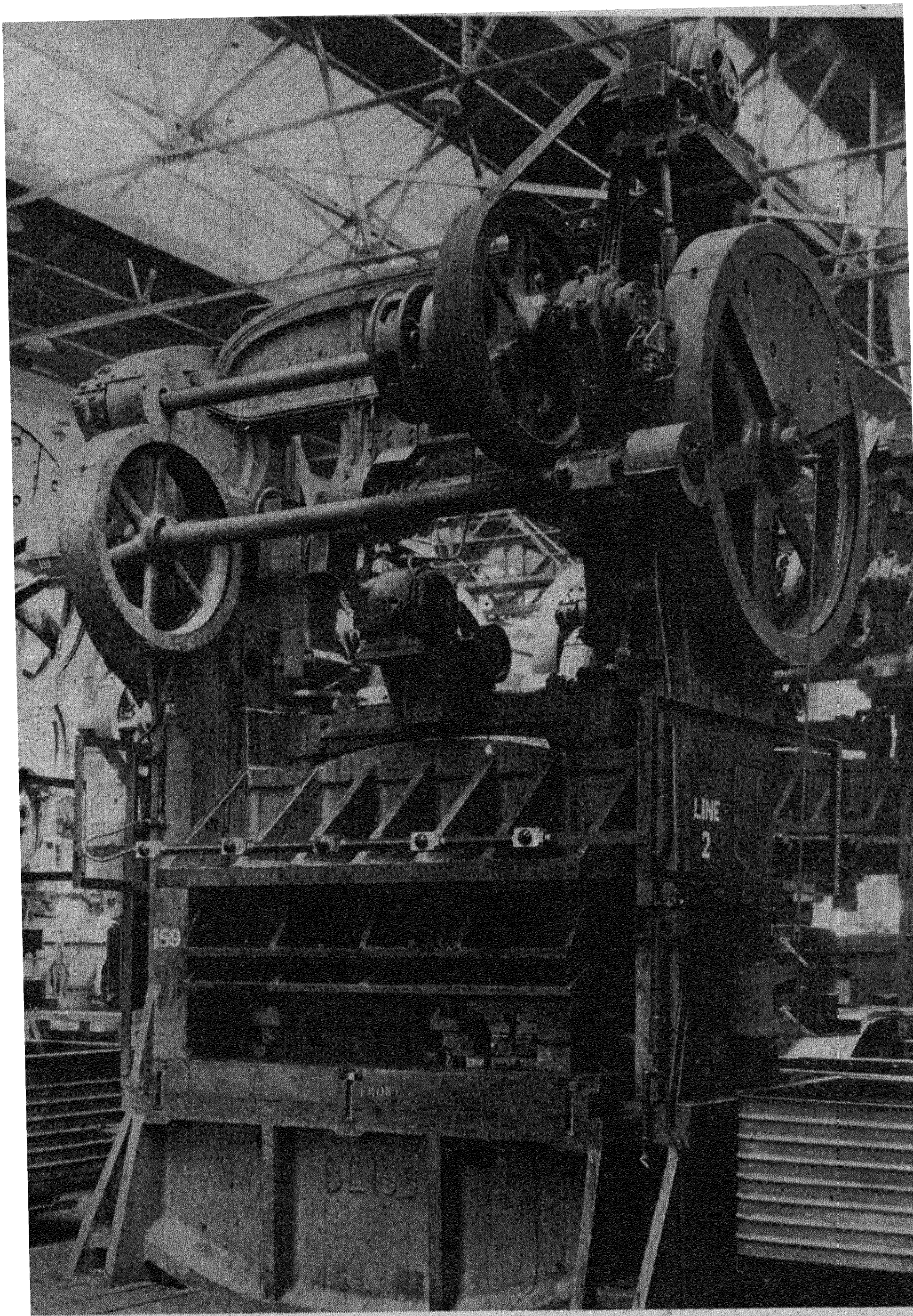


Fig. 17.—Double-crank press, tonnage about 150 tons
(*E. W. Bliss (England), Ltd.*)

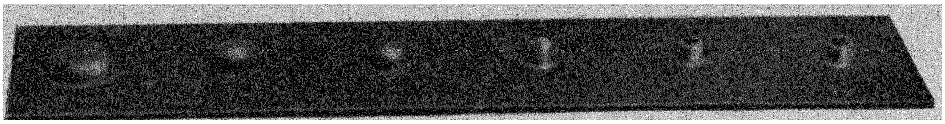


Fig. 18.—Sequence operations in forming and piercing a centre boss

are typical of coining work. The die entirely confines the blank and forces it to fill the recesses of the profile. Knuckle-joint-type presses for such work are usually selected on a basis of two or three times the static test load.

Embossing dies of male and female type for ornamental box covers, hollow silverware, embossed army buttons, etc., while they do not change the metal thickness appreciably, still must pinch it to a flowing pressure all over to bring up sharp impressions. Such dies are not closed at the sides, but, due to the thin section of the metal compared with the area, will act as closed dies.

Stamping dies for panels, beads, large letters, etc., when striking home solidly, instead of being built as drawing dies which cannot hit home, can build up a pressure higher than the coining pressure over the whole area, the metal being too thin to allow flow relief. It is better in such work to relieve or undercut the entire surface, leaving only a narrow line around the edges and corners to strike.

Extrusion

The fourth group in the squeezing series and the severest of all press operations is extrusion. Here the metal is forced to flow rapidly through an orifice, being otherwise confined and subject largely to the laws of hydraulics. Power-press extrusion is limited to tin and lead principally, aluminium, copper, and warm zinc occasionally, and hot steel experimentally. A modified crank press is a recent development for extruding collapsible tubes, and has shown good results. It brings the punch to rest as it touches the metal, removing the shock, and then extrudes with a slight acceleration followed by a uniform travel.

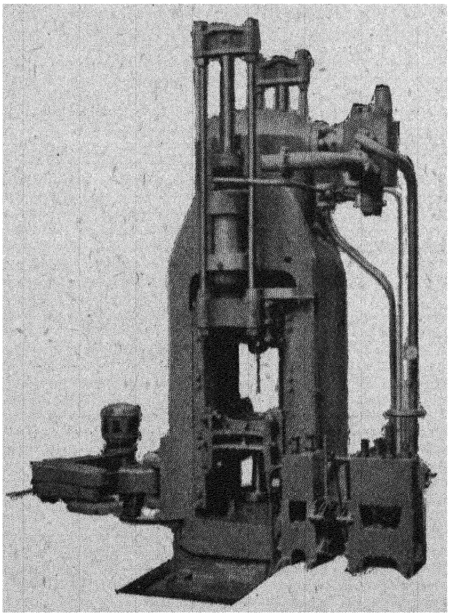


Fig. 19.—Vertical extrusion press of 1,250 tons capacity (*Fielding & Platt.*)

Welding rods may also be fluxed by extrusion, by using special dies in crank presses.

TYPICAL APPLICATIONS OF POWER PRESSES, WITH OPERATIONAL NOTES

Power Presses in the Motor Industry

In the motor-car industry, development in recent years towards simplification of operations has led to the welding together of stampings of the type that ordinarily required extensive hand-finishing. The ultimate goal was to make these larger units in as few stamping operations as possible in order to minimise or eliminate costly hand-finishing work. Another result desired and obtained by this procedure was that large motor-car body parts made in one die attain a uniformity which materially reduces the time, and therefore the costs, of assembly. The net result of this development is speedier production with lower costs and a much better finished job.

Deep-drawing Stock

Several problems had to be solved, however, before these large stampings could be made : First, the size of steel sheets of suitable deep-drawing stock had to be increased. At first this was a difficult problem for the steel mills, but one which they have now overcome. Also, the deep-drawing quality of the stock had to be improved to make deeper draws possible while retaining the smooth surface of the steel, thereby eliminating costly polishing operations.

In the rolling of these large sheets, the question of evenness and thickness over the entire sheet became of even greater importance than on sheets of smaller size. Variation in thickness at the edges and at the centre of the stock constituted a difficult problem for the steel producers, but it had to be corrected because of the obvious difficulties caused by that condition in properly spotting and fitting the dies. Also, it resulted in much waste due to breakage and increased cost of metal finishing because of the variations and irregularities in the surface of the metal.

Puckering and Splitting

Another problem that confronted manufacturers was the puckering and splitting of large automobile panels at such places as the corners of lights and doorways. This necessitated the annealing by hand of these spots and was carried out by a welding torch.

It was found that a cleaner and smoother finish resulted from this process and splitting was eliminated.

Constant research and improvement in the equipment of the steel mills have made it possible, however, to furnish the automobile industry to-day with the material required for the production of these large panels.

Dies for Larger Panels

The second problem was one which the car makers had to solve themselves : namely, the division of the body into fewer and larger panels and

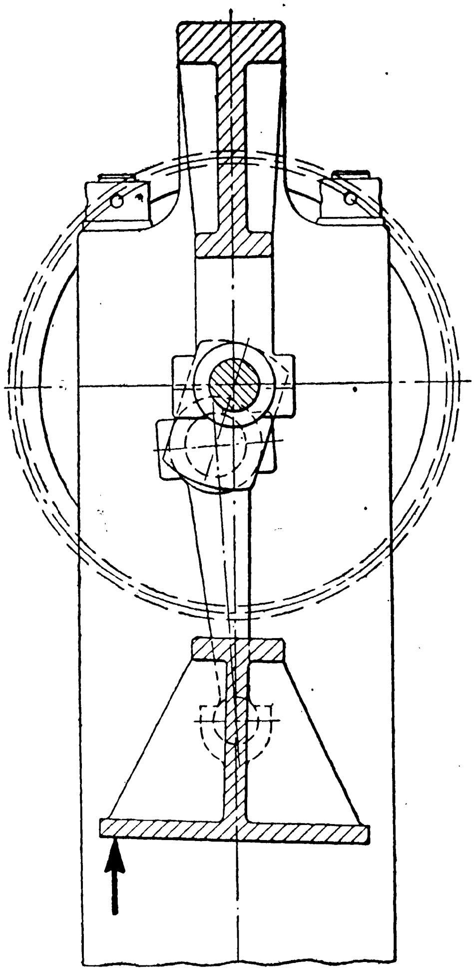


Fig. 20.—CRANKSHAFT RUNNING THROUGH THE CENTRE LINE OF THE PRESS FROM RIGHT TO LEFT

the production of dies capable of handling them. The body die-makers were equal to the new demands upon them and the evolution of that industry, extending over many years, has opened an ever-widening range for the motor-car body designer, so that stampings of a depth and size which it would have been almost impossible to produce several years ago are being successfully produced in one operation.

Being able now to obtain suitable sheet steel and having learned to build dies which would produce the large units, big stamping shops were confronted with the additional serious problem of procuring presses capable of utilising the new dies and the larger sheets to their full possibilities. Some of the press equipment installed in these plants was originally designed for the production of smaller pieces, but more important even than the size of the equipment was its inadequacy from the standpoint of accuracy and power application necessitated by this new development of large stampings.

Merely to increase the size of the presses was not the answer. One of the chief difficulties with some of the older press equipment was that the slide of the press carrying the upper die would not remain parallel during the entire stroke (particularly at the bottom of the stroke), which made accurate work difficult.

The uneven pressure distribution required over large areas by reason of the various odd shapes of the stampings made it absolutely necessary that the lower face of the press ram remain parallel with the press bed under these uneven load conditions. Particularly was this apparent in the case of dies of considerable width from front to back.

One type of press used at that period was driven from a crankshaft running through the centre line of the press from right to left, with the

pitmans connecting the crank with the slide actuating the movement of the slide at the centre line (see Fig. 19).

With this type of press construction, the problem was to eliminate the tilting of the slide when high pressure was exerted at either the front or the back of the stamping.

To obtain uniform stampings, it was necessary to "set" the metal at the bottom of the stroke to keep it from springing back out of shape after the stamping or drawing operation had been completed. This was especially important where beads in the stamping had to be set down sharply and where these beads were unevenly distributed over the face of the part, particularly in cases where such beads occurred on only one side of the piece (see Fig. 20). Not only for reasons of accuracy and uniformity of the work was it desirable to produce a sharp bead, but also for the sake of finish and appearance.

Crank-operated Four-point Presses

One of the first presses used for motor-car body work built on the four-point suspension principle and actuated by four connections, one at each corner of the slide (Fig. 21), was developed under the supervision and direction of the Clearing Machine Corporation, Chicago.

It was at first used only on single-action presses, and thus employed, the four-point suspension principle of actuating the slide solved many difficulties for the die designer and pressed-metal production departments.

While presses with the slide actuated by two parallel crankshafts were a distinct advantage over the design with a single crankshaft in the centre of the slide, the problem of equal power distribution to each corner of the slide, and also the elimination of bending, however slight, of the shafts under high pressures, presented an interesting subject for press engineers.

The constant advance in quality and uniformity of the large sheets which were by now being produced, and also the forward steps in die design, meant that the press builder had to adapt his equipment to meet new conditions. Deep draws on one side of the stamping, sloping to shallow curves on the other side, might be one condition, or the setting of the material at the bottom of the stroke of the press. Again, only one corner of the

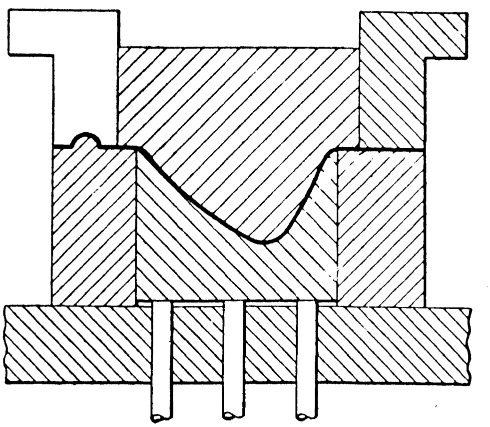


Fig. 21.—"SETTING" OPERATION

In some cases, e.g. where there is a bead on one side only, this setting is necessary to prevent the stamping from springing back out of shape.

stamping might require that the fact of excessive torsional deflection on the crankshaft (or the deflection of the press under load) be minimised. The problem of torsional deflection in crankshafts is a serious one. Constant shocks and the twists developed in handling the present-day type of work cause fatigue in the metal, causing broken crankshafts.

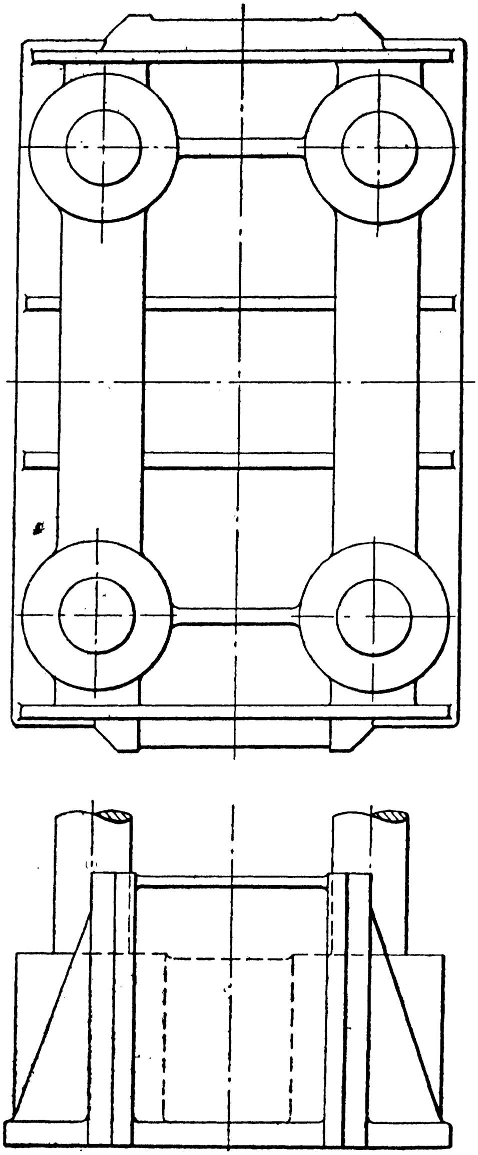


Fig. 22.—FOUR-POINT SUSPENSION PRESS

The Crankless Press

Everyone familiar with the high-pressure demands of periods of peak production in the motor-car industry will realise that such interruptions in production lines, to say nothing of the cost of repair, constitute one of the weak links in stamping shops. These difficulties are most serious when the crankshafts break on the large presses, and so the Clearing Machine Corporation, Chicago, has developed a type of crankless press which is now being used for this type of work (Fig. 23).

On this type of press, each corner of the slide has its individual drive symmetrically distributing power from a central point, namely, the motor and flywheel. The bull gears, which on other presses were mounted at the ends of the driveshaft on the outside of the press, are directly over the four corners of the slide in the "crankless" press, resulting in a direct transmission of power and the absence of excessive torsional deflection.

Eccentric and Bull Gear

Integral with the bull gear, in one solid steel casting, is an eccentric, varying in diameter according to the stroke requirements of the slide, and this eccentric and bull gear revolve over a non-rotating, large pin (Fig. 24).

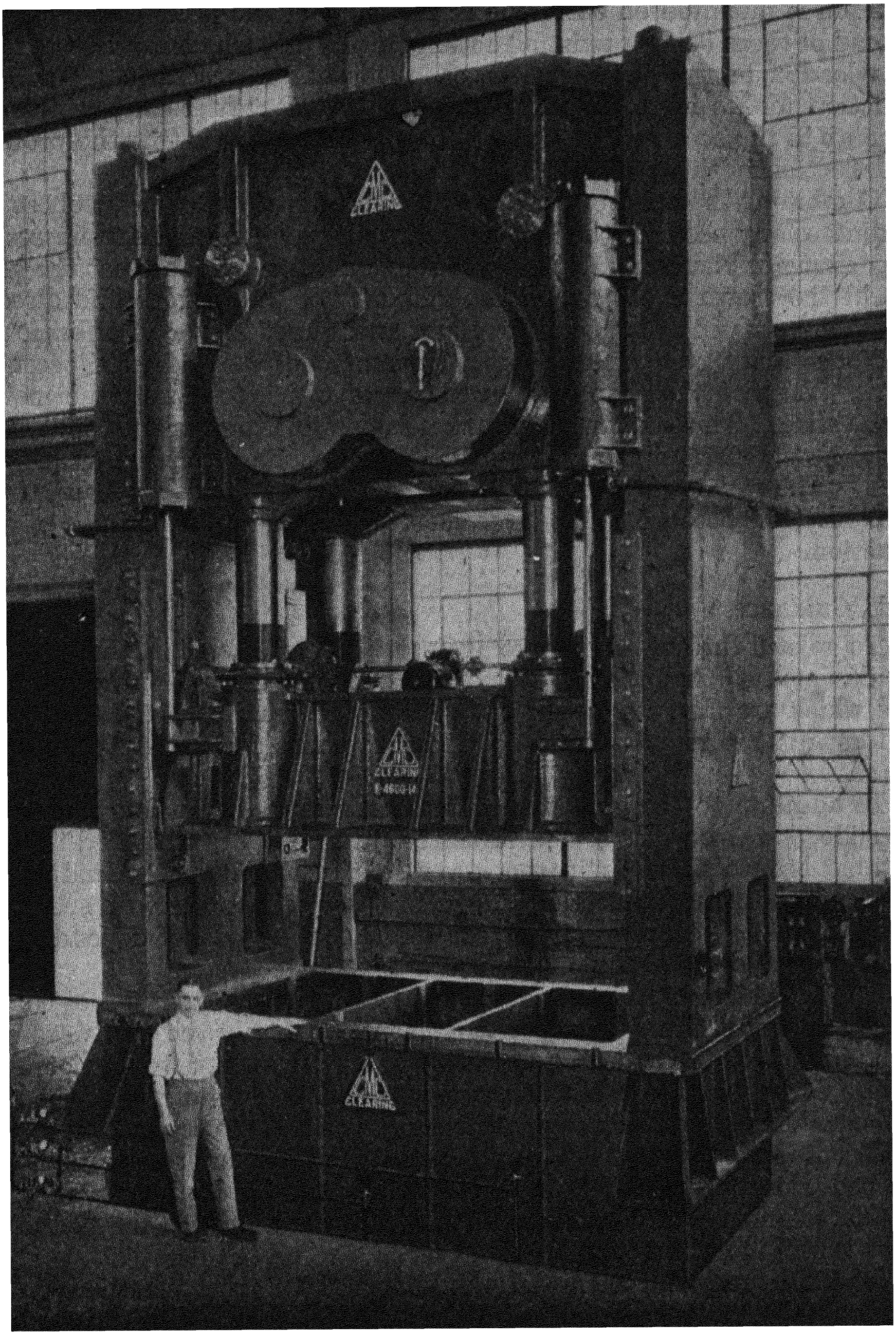


Fig. 23.—CRANKLESS PRESS FOR THE MOTOR INDUSTRY

Each corner of the slide has its individual drive symmetrically distributing power from a central point.

This pin is mounted on each side in the walls of the press crown so that instead of there being a twisting action on this pin, which carries the load, it is loaded in straight shear, on each side of the eccentric. This construction makes it possible to shorten this load-carrier pin, bringing it close up to the eccentric, thereby almost entirely eliminating the problem of deflection in this member.

Combining the main bull gears with the eccentric into one steel casting eliminates any need for the keys ordinarily used on crankshaft presses for the driving of the crank. From the foregoing it is evident that the gearing in the crown is all within the boundary of the tie-rods and directly over the actuating members for equal and direct power distribution.

For actuating the up-and-down movement of the slide, the eccentric carries an eccentric strap, the lower end of which transmits the motion to the slide. This construction makes it possible to eliminate split bearings, the eccentric strap being made solid in one steel casting, bronze lined. The square-inch pressure loads on these main bearings are, therefore, very low because of the large surface obtainable in this type of construction.

Slide Guidance

To go still further and assure against tilting of the slide, these presses are designed so that the slide guidance does not depend entirely on the gibs which are fastened to the uprights of the press. In the first place, all four gibs are made adjustable. This provides accurate alignment for the slide.

In addition to the gibs, the connection screws at the four corners of the slide, which provide for its vertical adjustment, are extended through suitable bronze bearings in the lower side of the crown. Guiding the upper end of these connection screws in these bronze bearings set in the crown provides accurate guiding for the slides, instead of depending for its guidance on the gibs alone.

The gibs have to be maintained in a loose enough position, of course, with sufficient clearance for free movement, so if only the gibs were used for guidance of the slide the accuracy of its alignment would not be as precise as by the above method, with its additional guiding of the slide in the solid crown of the press, at the upper end of the connection screws.

If it is important to keep the slide of a single-action press parallel with the bed of the press, it follows that in the case of a double-action press, parallel alignment of both slides with each other and with the bed of the press is still more important.

To hold the blank accurately and exert the correct pressures on the draw ring, the advantage of using the four-point suspension principle on the blankholder slide has long been recognised, and four adjustment screws, one on each corner of the slide, have been employed for this purpose for many years.

A dependable means of obtaining a parallel position of the slides during operation is the four-point suspension principle of power-press drive.

In actual experience, double-action and triple-action presses thus constructed, with all slides guided at each corner of the various slides, have resulted in great accuracy for the stampings and less wear on the dies.

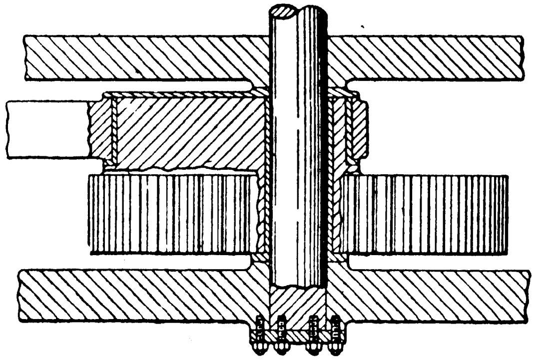


Fig. 24.—SECTION OF ECCENTRIC INTEGRAL WITH THE BULL GEAR WHICH REVOLVE OVER A NON-ROTATING LARGE PIN

Oil Receptacles

The construction of a press crown in the manner described above provides an oil receptacle for all of the rotating parts of the press, greatly simplifying lubrication, which is so important on machine parts subjected to intermittent high pressures, as in the case of the parts on a large power press.

In this way dependence on oil feeders or forced grease lubrication is eliminated and long life of the vital working parts of the press is assured. It also eliminates the problem of depending upon the uncertain human element in connection with lubrication, particularly in the large shops where a great number of units would otherwise have to be attended constantly. For quick visual check, if desired, a sight glass is provided showing the level of the oil, which needs to be changed only occasionally.

At the lower end of each connection screw where it connects with the slide, slide-adjustment gears are provided, and to assure positive and accurate alignment of the four corners, individual adjustments for each of the screws are supplied, which makes it possible to align each corner individually by means of finely graduated adjustment devices.

Slides Counterbalance

Because of the increasing size of the dies used in connection with these large body presses, the slides are counterbalanced by means of compressed-air cylinders for smoother operation and protection against drop of the slide in case of brake failure. The air pressure can be regulated to suit the various die weights and to compensate for variations in the weight of the moving parts of the press.

At the upper end of the connection screw is a bearing in which the lower end of the eccentric strap swivels. These four cylindrical bronze bearings at the bottom of the crown are of considerable length and they carry at their lower end an oil-retainer ring.

Chapter V

DEFLECTION IN PRESSES AND DIES AND DIE-CUSHION EQUIPMENT

SOME press manufacturers publish tonnage ratings for their presses only with reluctance, if at all. The rating must be varied to suit the work.

Many users of presses still believe that if a press does not stall or break on a job it is perfectly suitable. That is only part of the story. The expressions " stiff " and " rigid " are not mere catchwords in describing a press, but neither can they be accepted literally without reference to load and work to be done. A press may be as stiff as it is practical or even possible to make it, capacity and range being considered, yet not stiff enough for any extra-heavy work which it may be called upon to do.

The materials used in press construction are elastic. They must be, to stand shock loads. When a load or pressure is applied they stretch, bend, or compress, the distortion increasing in proportion to the increase in load. That is common knowledge, of course, but a press appears so massive that the fact is readily overlooked.

Gap-frame Presses

The gap or overhanging type of frame which characterises inclinable presses and end-wheel punch presses, etc., is very convenient for feeding purposes and hence very popular.

Spring or deflection which is not straight but on an arc is an inherent characteristic of this type of frame. The spring may be more or less according to details of the design, but unbalanced spring goes with any C frame.

On bending and drawing work and some stamping and shearing jobs such spring may not make any difference. On blanking where the clearance between punch and die is large compared with the eccentricity of the deflection, it may not do much harm. But if a fine die with small clearances is put in such a press, loading it to capacity, the life of that die will almost certainly be cut to a small fraction of what it should be.

The fault is not in the press, but in the selection of the press. An instance occurred in which it seemed possible to get only about 15,000 punchings per grind out of expensive blanking and perforating dies. The engineer advised trying the die in a press of the same type three sizes heavier, although the original press did not seem to be labouring in the least. The result was an increase to around 150,000 punchings per grind.

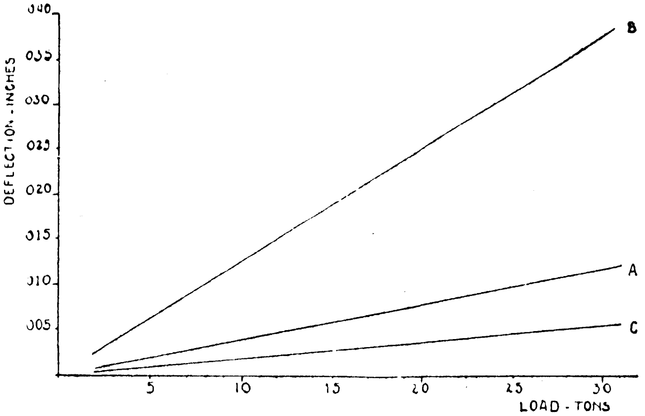


Fig. 1.—THE DEFLECTION OF THE FRAME (A) AND THE COMBINED DEFLECTION OF THE FRAME AND WORKING PARTS (B) BOTH RISE IN PROPORTION TO THE LOAD

The die upkeep saving exceeded the price of the press several times a year.

Fig. 1 is a graph showing the deflection at three points on a substantial C-frame press of the short-throat inclinable type. The chart is taken from a recent group of comparative tests made at the E. W. Bliss Company. Fig. 2 shows the positions of the indicators in taking the readings, and exaggerates very much the change of position of the frame and slide to indicate the directional tendency. The curve A shows spring of the frame as the load is applied. Curve B shows spring of the slide relative to the bed and is a combination of the frame spring plus the take-up of bearing clearances. The curve C is an index to the relative angular change between the surface of the bed and the surface of the slide. Its maximum reading is equivalent to an angular change of about three minutes between the two surfaces.

Note that there are two types of spring present, arc spring in the C frame and straight spring in the moving parts (straight with relation to the slide ways and the upper part of the frame).

The arc spring changes the relative angles of the punch and die-holding surfaces as the load comes on, and

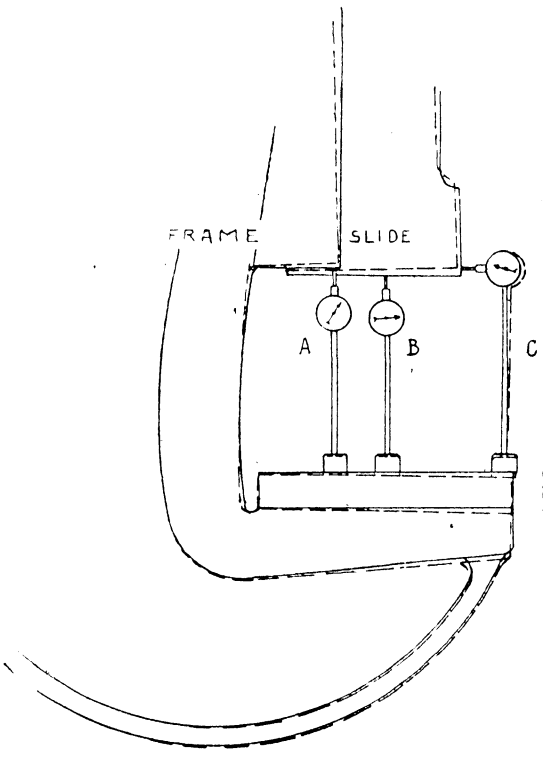


Fig. 2.—ELASTIC DEFLECTION OF THE PRESS PARTS (MUCH EXAGGERATED) AND THE POSITIONS OF THE INDICATORS IN TAKING THE READING.

therefore alters the (front and back) clearances in fine blanking dies or causes a stamping die to pinch tighter at the back than at the front unless compensation is made. The change of course is small and is in proportion to the load.

The straight spring in no way affects the change of angle, but does add to the snap-through effect on blanking dies and also adds appreciably to the power consumption in that the working load must be applied through its normal working distance plus the distance that the press springs.

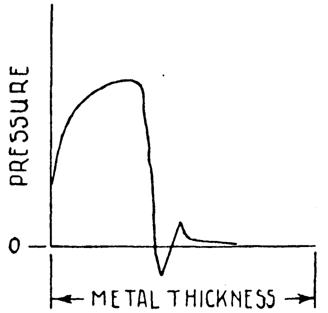


Fig. 3.—An indicator diagram of a punching operation showing the snap through and rebound due to frame spring

Fig. 3 is a graphic chart of the pressure during a blanking operation. The sudden jump of the punch at the instant the blank fractured and pressure was released caused the indicator pencil to oscillate across the neutral line. The press spring causes the punch, when released by the fracture, to snap through the remainder of the work and the die at a speed instantaneously much above normal. The effect is clearly detrimental to the cutting edges, probably due to increased heating and abrasion.

Note that increasing the length of the slide and ways beyond a normal length obviously does not in any way affect either the straight spring or arc spring. Note also another fallacy :

Rods between the bed and the top of the press at front are sometimes tried, to prevent arc spring. Being steel they are more elastic than the cast iron or semi-steel of the frame. In Fig. 4, which is a cross section just above the bed of a typical gap-frame press with tie-rods, compare the cross-section area of the frame, on one side of the working centreline, with the rods on the other side. Clearly such rods will not balance the frame. If the rods are put under sufficient initial tension to take an appreciable portion of the load, they will spring the frame together under no-load conditions. It is possible of course to shrink the rods in against properly fitted spacers, but that is semi-permanent, and it would be better to resort to another type of press.

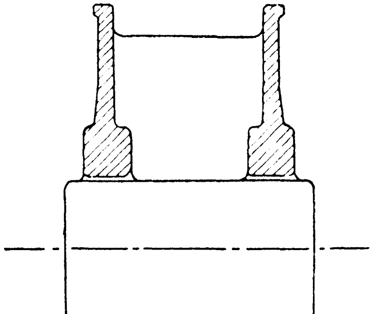


Fig. 4.—Comparing the cross section of frame and rods to show how little front rods can do towards balancing the loads on C frames

One more comment should be made with regard to gap-frame presses. Where arc spring is reducing the die life it may not be enough merely to go to a larger size press of the same type. As the size of C-

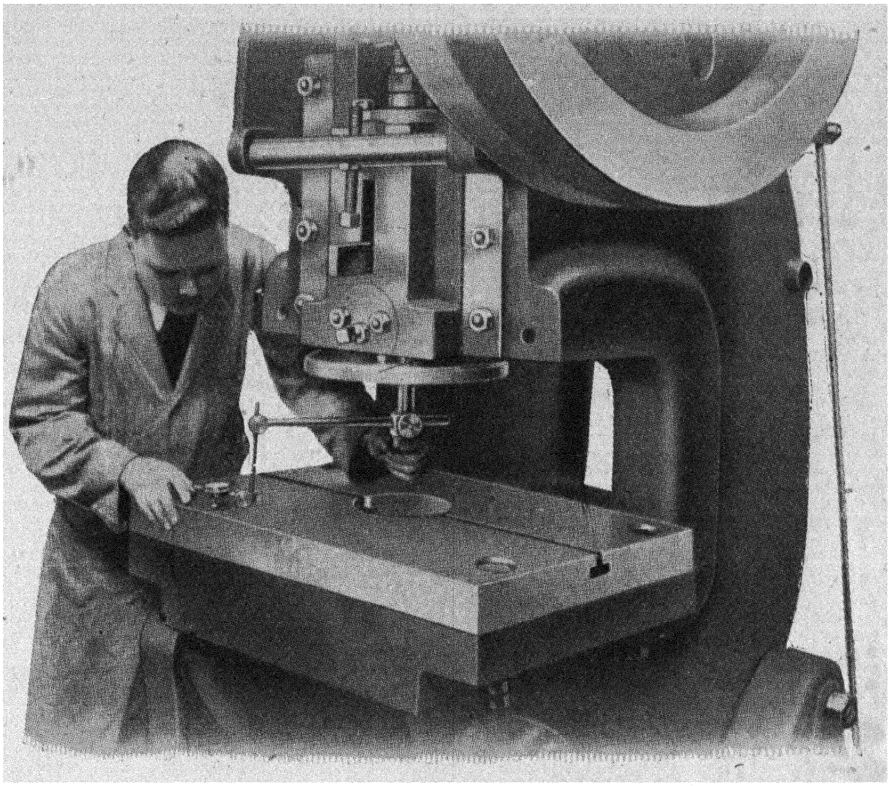


Fig. 5.—An engineer testing a press for deflection

frame presses increases, the depth of throat also increases in many lines. The result is that the stiffness at any given load does not increase as much as might be expected, from one size to the next. Thus in one line the frame of a press of about 35 tons peak load will spring ·0065 in. at 25 tons, while at the same load the 50-ton size shows ·0060 in. deflection.

Straight-sided Presses

Many presses are built with straight columns connecting the bed and working parts of the press, and centrally located with reference to the working centreline. Thus any properly placed load within the capacity of the press will cause straight vertical spring only. The columns are massive, but they will stretch to an appreciable amount at full load. There is no arc spring, however.

The large tie-rods on a 100-ton single-crank straight-sided press would stretch about forty thousandths of an inch at full load if they were merely tightened in place. Instead they are shrunk in by an amount considerably greater than that. This creates a tension in the rods higher than the working load, and is exerted in pressure on the cast-iron side-frame

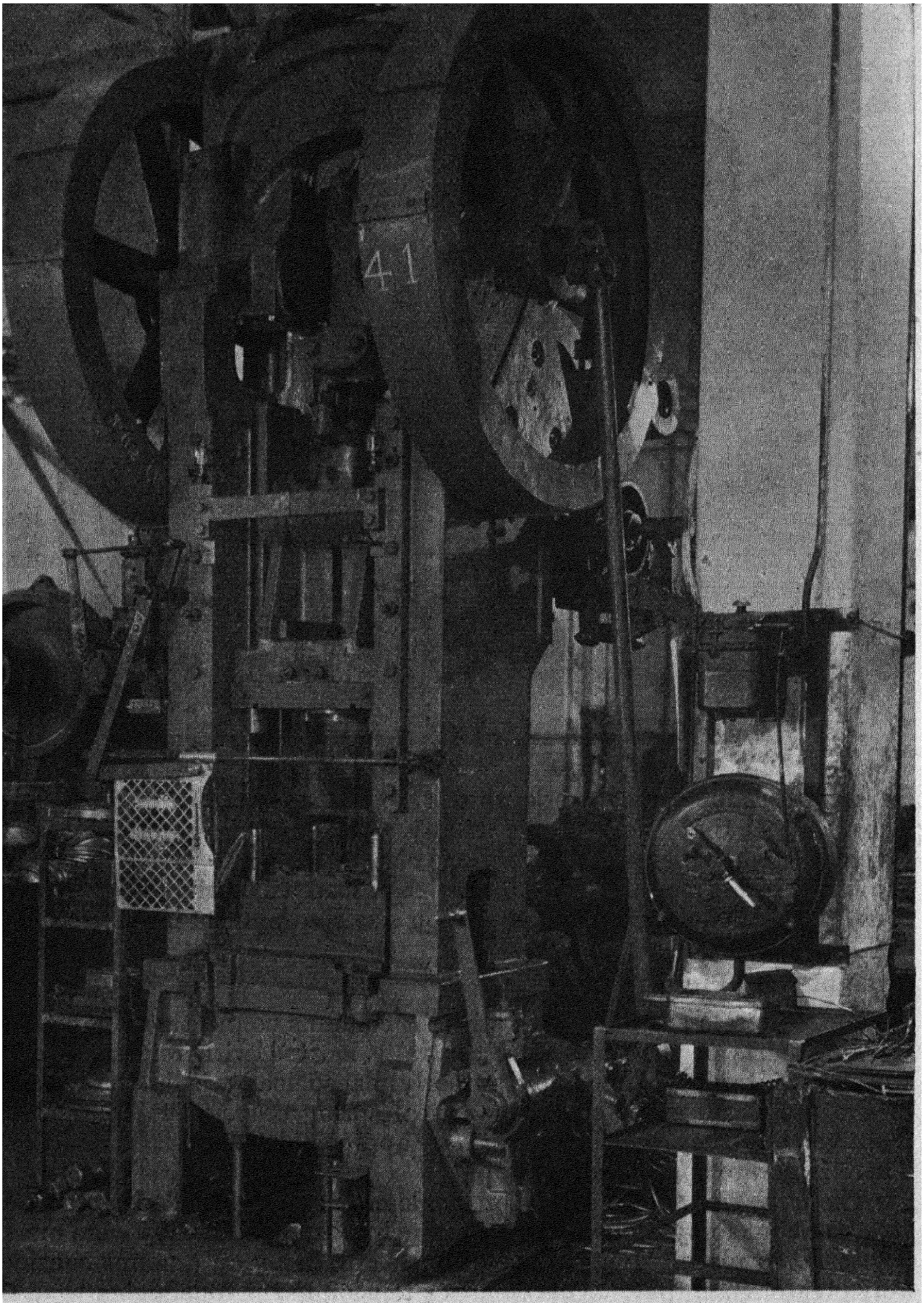


Fig. 6.—Reducing press—tonnage about 90 tons at bottom of stroke
(*E. W. Bliss* (*England*), *Ltd.*)

columns. As the working load comes on, the working parts of the press (connections, slide, and tools) merely relieve the side-frame columns, taking over a portion of this pressure, but do not stretch the rods farther. That portion of the working spring or stretch residing in plain cast side columns is thus practically eliminated.

On wide presses of the double-crank type the long bed and slide are another source of deflection or spring. On this type of press, if the full load was concentrated at the centre, the total deflection in the bed and slide might total twenty thousandths of an inch. This amounts to comparatively little on such a press except on some stamping and drawing jobs.

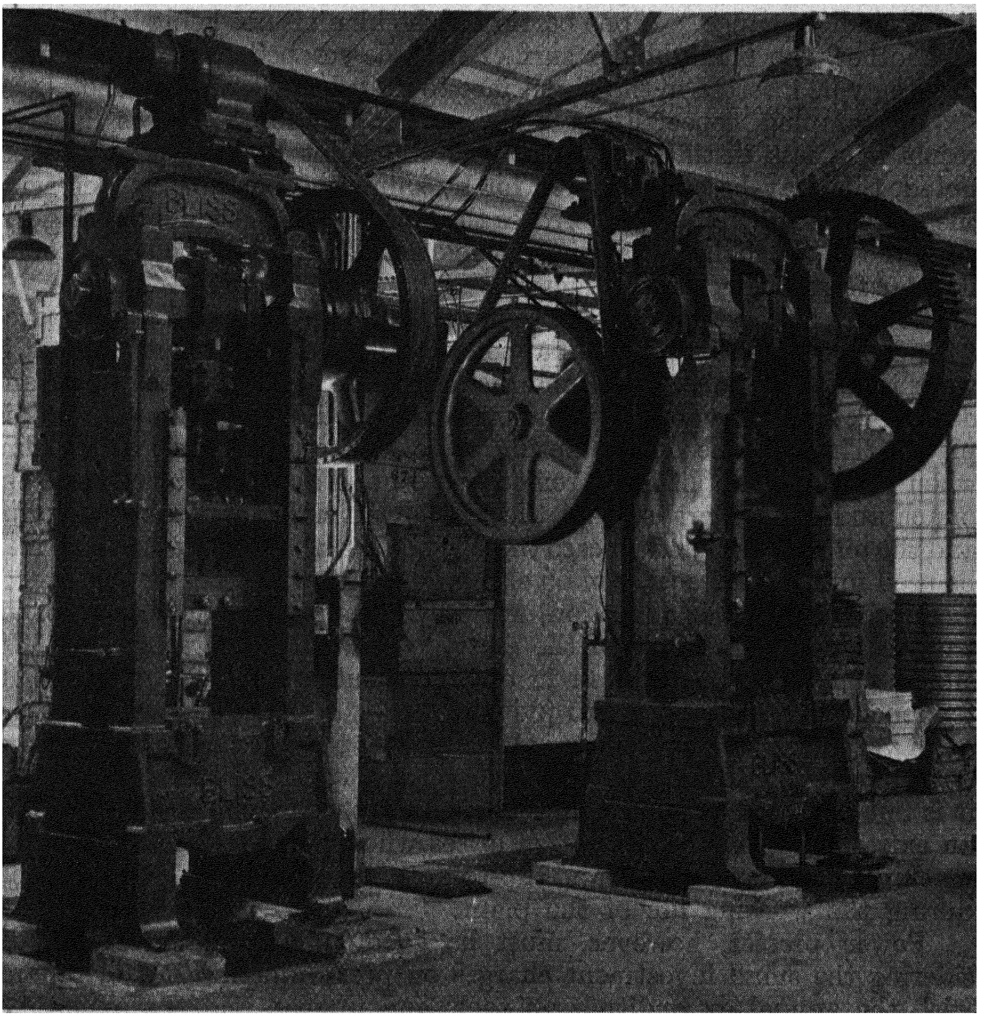


Fig. 7.—SINGLE-CRANK PRESSES—90 AND 120 TONS RESPECTIVELY

(*E. W. Bliss* (*England*), *Ltd.*)

Effect of Press Deflection on Dies

With reference to blanking or punching dies, it has already been noted that the arc spring of a C frame changes or shifts the clearance between the punch and die, so that if the clearance is small and the spring is considerable, excessive wear may readily result. It has also been noted that straight spring will cause the punch to snap through the die as the strain on the sprung members is released by the fracture of the work. This is a maximum where there is no shear on the dies and the clearance is large enough to permit a free clean fracture.

In drawing, the effect of deflection is rarely evidenced except possibly in an uneven blank-holding effect, particularly in drawing large-area shapes in light gauge. If one portion of the blank is not being held as well as another, the blank-holder surface may be scraped to suit, or a draw bead may be inserted in the die surface to retard the flow of the metal.

In stamping, especially over a considerable area, spring is liable to result in a less distinct impression at one point than at another. As noted, this may be compensated for by shimming but not by increasing the pressure, which merely increases the spring. Some straight spring will compensate for slight variations in thickness of material, though of course it is far from being a safety factor.

Coining and extrusion work require very high pressures as compared with other types of work. It happens in some cases where the metal in work is thin, that the punch and die surfaces may strike each other and damage lettering or designs if the press is turned over without a blank in place. This may be due to spring or to the squeezing out of oil films when the load is applied. A remedy is to build hardened blocks into the punch and die holders, so that the blocks will strike and take up spring and the oil film thickness in case there is no blank. A similar scheme may be used for extreme accuracy on sizing operations.

Machine spring or deflection, while by no means the only cause of die troubles and wear, is one of the most potent and least recognised. Its effects can hardly be figured in advance, but an understanding of its tendencies is a material aid to judgment.

A very false idea of economy often dictates the purchase of the lightest possible press. It is true that with certain types of engineering plant it is not regarded as good policy to manufacture machinery for too long an existence. This consideration arises when improvements to existing machinery, or even new and up-to-date designs, are apt to appear during the working life of the plant.

Power presses, however, must be good, and made to last. Considering the small investment charges on press equipment as compared with the annual expenditure on tools and upkeep and the expense of lost production time, the waste resulting from the installation, if too light or cheap a press for the work that has to be performed, is obvious.

Die-cushion Equipment

Die-cushion equipment is generally a method of providing controlled resistance by means of which a blank is automatically held in a grip—not too firm and not too light—to enable simple tools in a press to draw metal shells, or pressings, at higher rates of production. With their help single-action presses can be used in place of double-action presses and double-action presses in place of triple-action presses.

In the case of a double-action press, which works at approximately one-quarter the speed of its counterpart in single-action presses, a toggle-operated draw ring comes down to a point above the die face. This point is approximately the thickness of the metal being drawn and is controlled by the setter.

When a cushion-operated draw ring is employed, the die face grips the metal between itself and the draw ring with a predetermined pressure. That pressure comes into operation at approximately half stroke and continues throughout the drawing operation, and it can be fixed or varied, according to the type of control employed.

The pressure is not affected by the blank being thicker on one side than on another, nor is successive variation in the thickness of the blanks during the run of any importance. In fact, even if two blanks, or for the matter of that three, were inserted, the pressure would be the same.

There are several alternative ways of applying pressure-plate loading.

Springs

The difficulty when using a spring is that sufficient power cannot be brought to bear to effect the end in view. Another obvious objection is that as compression increases, pressure increases. If the pressure is correct at the beginning of the stroke, then it is too high at the end of the stroke and the pressing is liable to fracture. A weaker spring or one under less compression is liable to encourage wrinkle formation and consequent loss in output.

For this reason springs are only used on the smaller type of press, where the draws are not deep.

Hydraulic and Pneumatic Cushioning

Three systems are generally employed, namely, hydraulic, hydro-pneumatic, and pneumatic, and they cope with very heavy work, heavy work, and general work respectively. In the first system, oil or water is confined in a cylinder or cushion unit and the slide of the press in its descent forces this liquid out of the cylinder through a variable-orifice valve which is mechanically controlled. With the hydro-pneumatic system the oil or water confined in the cylinder or cushion unit is forced through a pneumatically operated variable-orifice valve into a receiver or tank partly filled with oil or water and partly by compressed air. This

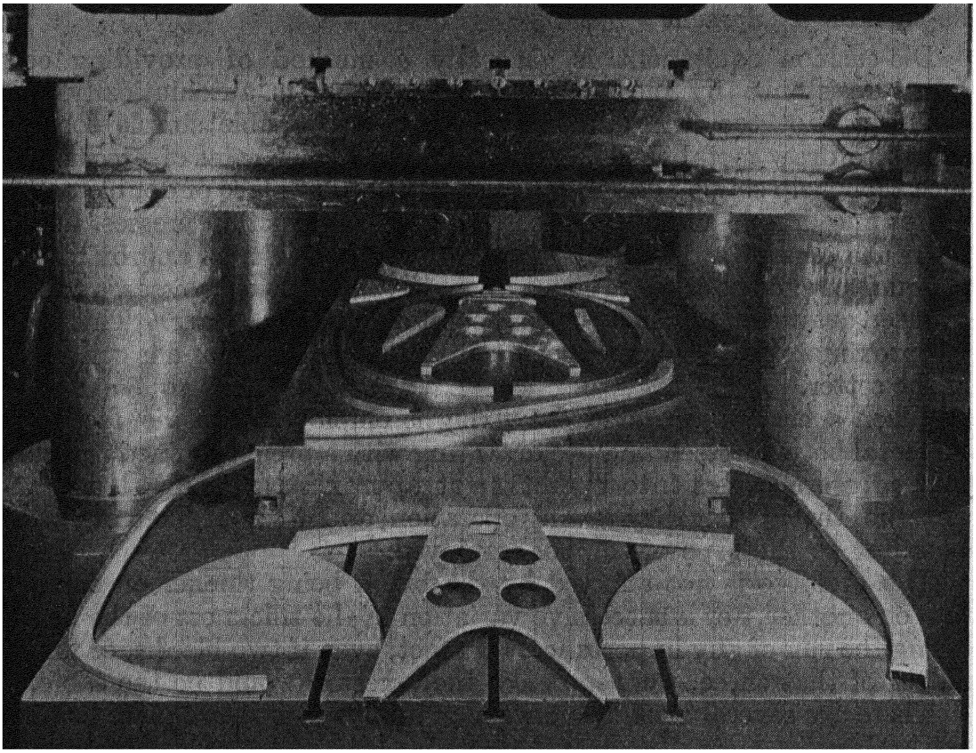


Fig. 8.—SET-UP OF THIRTEEN DIES ON THE PRESS TABLE OF A 4,000-TON HYDRAULIC PRESS
This press uses a thick rubber pad instead of the usual bottom-forming die.
(*Fielding & Platt, Ltd.*)

system permits much more accurate pressure control than the full hydraulic system. In the pneumatic system only compressed air is in the cylinder or cushion unit, pipe line, and receiver or tank. It provides an accurate and precise method of producing the required closely controlled resistance which is called for in delicate drawings. On the other hand, strong smooth pressings are produced on the same equipment up to the full capacity of the press. This pneumatic die-cushion equipment is used in the majority of the large and small press shops.

On the whole it may be said that the pneumatically operated cushions are the most satisfactory. They are the least likely to generate trouble within themselves. In the hydraulically actuated, for instance, it is only necessary for a valve to slip or become clogged for the whole unit to become solid, and both tools and presses can suffer considerably.

A very small compressor will serve a long line of pneumatic or hydro-pneumatic cushion equipments. Further advantages are the facts that pressings are ejected up to the full capacity of the cushion unit, whilst piercing, raising, coining, and clipping may be performed in the same stroke as the draw, right up to the maximum capacity of the cushion unit.

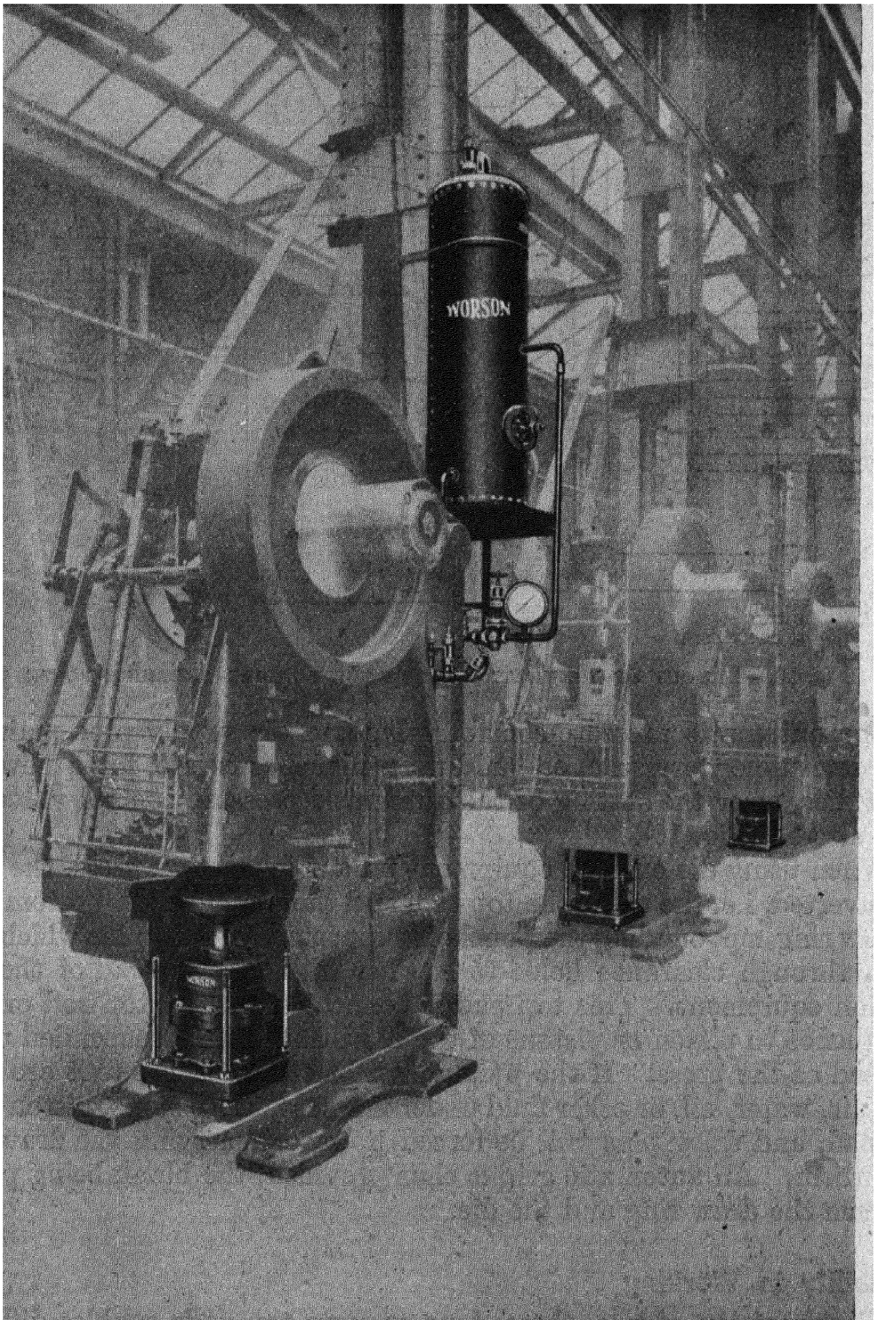


Fig. 9.—Group of power presses, each with pneumatic die-cushion equipment, controlled from a common system

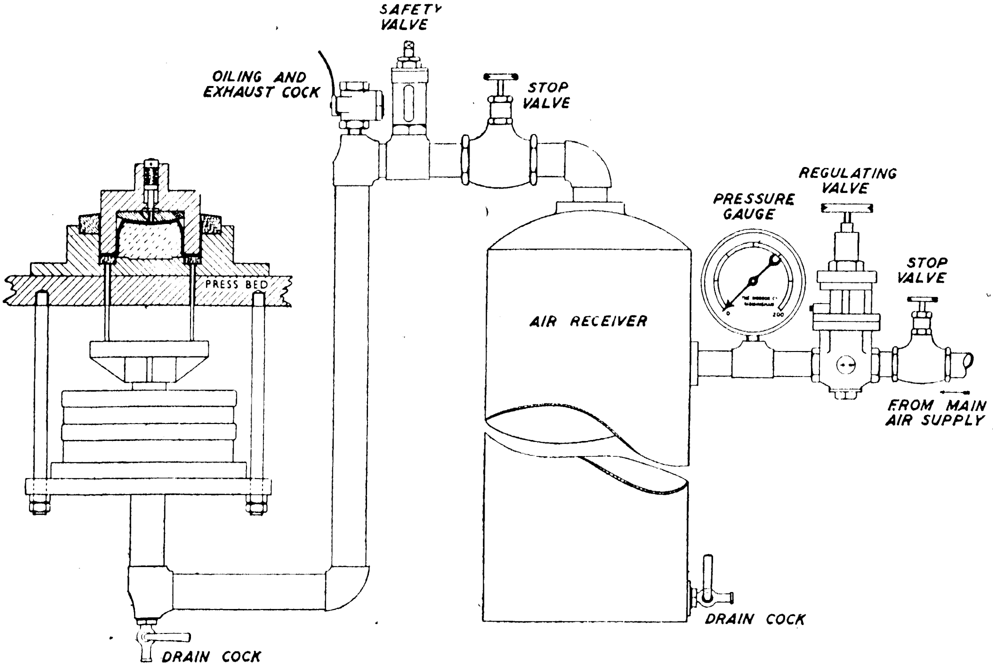


Fig. 10.—LAYOUT OF PNEUMATIC SYSTEM FOR LOADING PRESSURE PLATE

The automatic pressure-control valve and air supply pipe maintain a predetermined pressure, or build up a higher pressure, for a new set-up of dies, after the setting of the automatic pressure-control valve has been altered (Fig. 10).

When using die-cushion equipment on a single-action press, the tools are inverted, i.e. the die is the top tool and the punch is the bottom tool. A draw ring, surrounding the punch, is supported on draw pins which pass down through clearance holes to contact with the top pad of the die-cushion equipment. This top pad is connected with piston rod or rods and thence to piston or pistons of the die-cushion unit, suspended under the bed of the press. If the cylinders in the die-cushion unit are filled with air, water, oil, or other fluid under pressure, the pistons, piston rods, top pad, and draw pins will be forced upwards, carrying the draw ring with them. An automatic grip is thus provided, the blank being placed between the draw ring and the die.

Flexibility in Working

The provision of two, three, four or more top pads enables different pressures to be obtained over the surface of one or more dies. Simple or combined sets may have a simple or fully universal and automatic control fitted which permits the pressure to be decreased, increased, or eliminated entirely at any desired point of the stroke. Other types of equipment

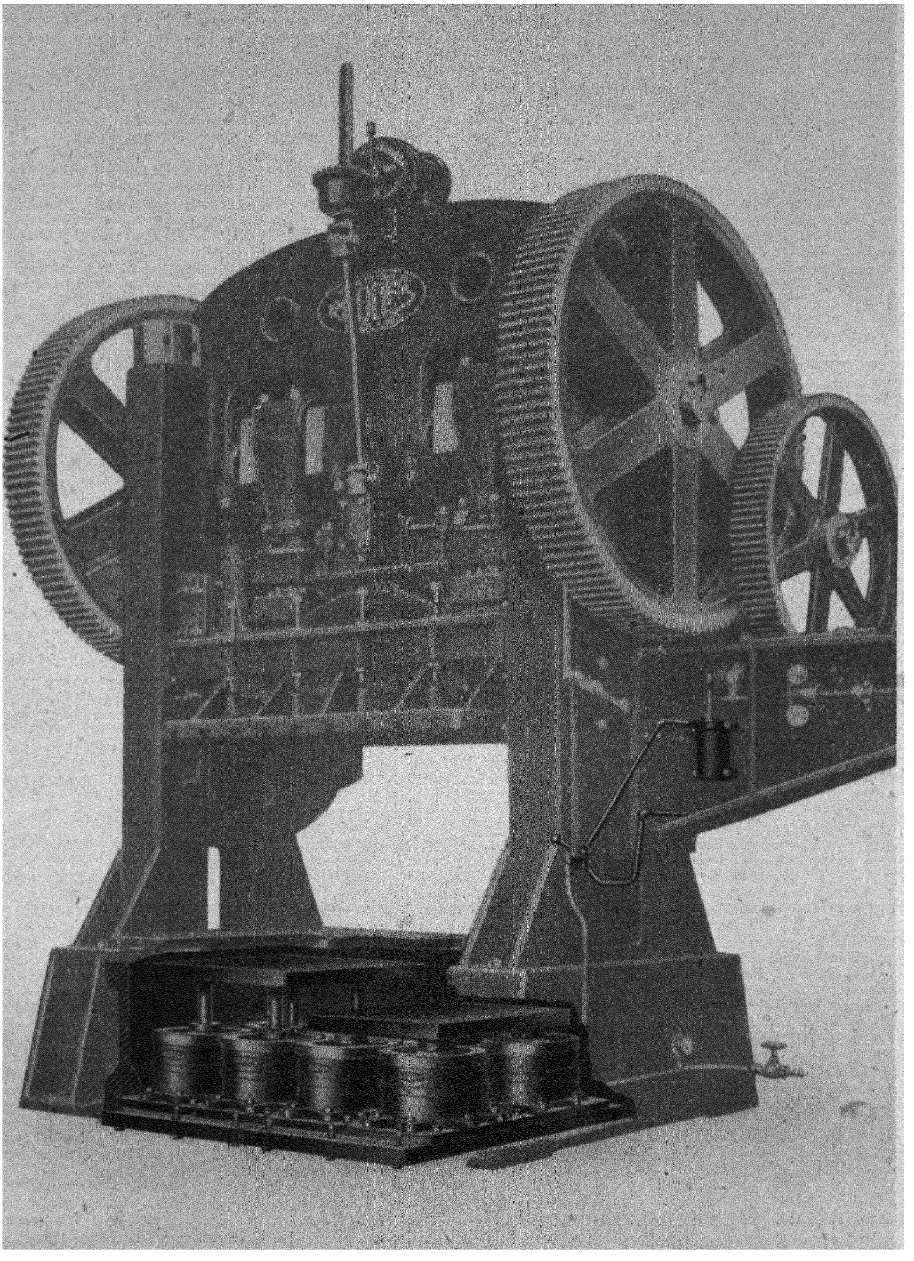


Fig. 11.—A 300-TON DOUBLE-CRANK DOUBLE-SIDED RHODES PRESS WITH DIE-CUSHION EQUIPMENT, THE PRESSURE BEING APPLIED BY THE PNEUMATIC LAYOUT SHOWN IN FIG. 10

provide for the case of a pressing which may be drawn and pierced in one stroke and the resultant piercings dropped through the tools, press bed, and cushion unit to the floor or scrap bin. In the case of multiple-top pad equipments, several sets of tools can operate at once on blanks of the same or different thicknesses on the bed of a large press. Pressings are held perfectly flat, thus avoiding hand labour for "setting" such parts as gramophone turntables; stove, refrigerator, and wireless cabinet panels, doors, etc.; brackets for the general pressing, motor, and aircraft industries, etc.

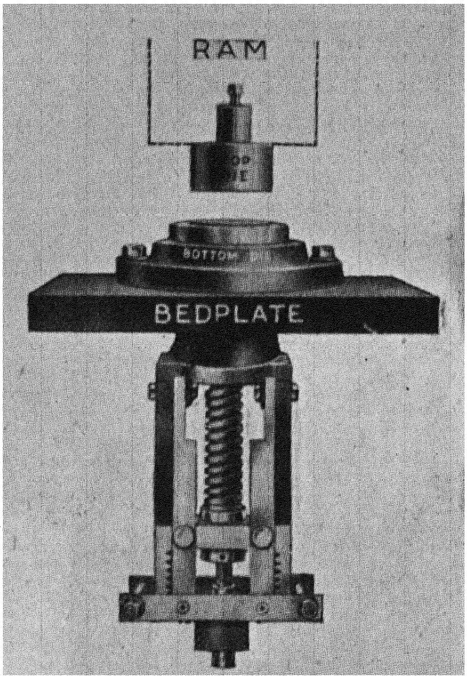


Fig. 12.—The "Simplex" drawing device, a self-contained portable unit which enables a single-action press to do the work of a double-action machine

Adjustment of Pressure-plate Loading

Since the pressure per square inch of the fluid member is accurately and automatically controlled, a pressure is exerted on the blank which is not so large that the metal bursts or tears when being drawn over the punch, and not so light that it puckers in the process. The pressure exerted is controlled by means of an automatic regulating valve which holds the exact pressure desired; this can be read on a gauge and be recorded on the tools for reference, so that in a future working they may be set up again without experiment. Drawing tools may therefore be set up in the same time approximately as blanking tools, as the blank is held at a predetermined pressure and not at a predetermined point of the stroke. This fact avoids the waste of many hours which may be spent in adjusting a mechanical draw ring and those strains on the press caused by variation in blank thickness.

A Mechanical Drawing Device

The Rhodes "Simplex" drawing device, shown in Fig. 12, is entirely mechanical, and it is claimed that the pressure on the blank is constant throughout the stroke. It is self-setting and an entirely self-contained portable unit which obviates the need for air-pressure equipment. Additional advantages claimed are higher rate of out-

put, reduction in the percentage of wasters, and economy in the time of die setting. Fitted to a single-action press it enormously increases the range and enables general drawing work to be done without a double-action press.

A tube is fixed into the bedplate of the press. And on this tube the device hangs and operates. In the tube is a rod which is screwed into the forming block of the bottom die so that the forming block moves upwards instead of remaining fixed. In operation the pressure pins force the plate downwards and racks force the rod which is within the tube upwards. With the descent of the punch, the forming block in the bottom die moves upwards in step with it. The pressure on the blank required to operate the device suffices to prevent wrinkle formation.

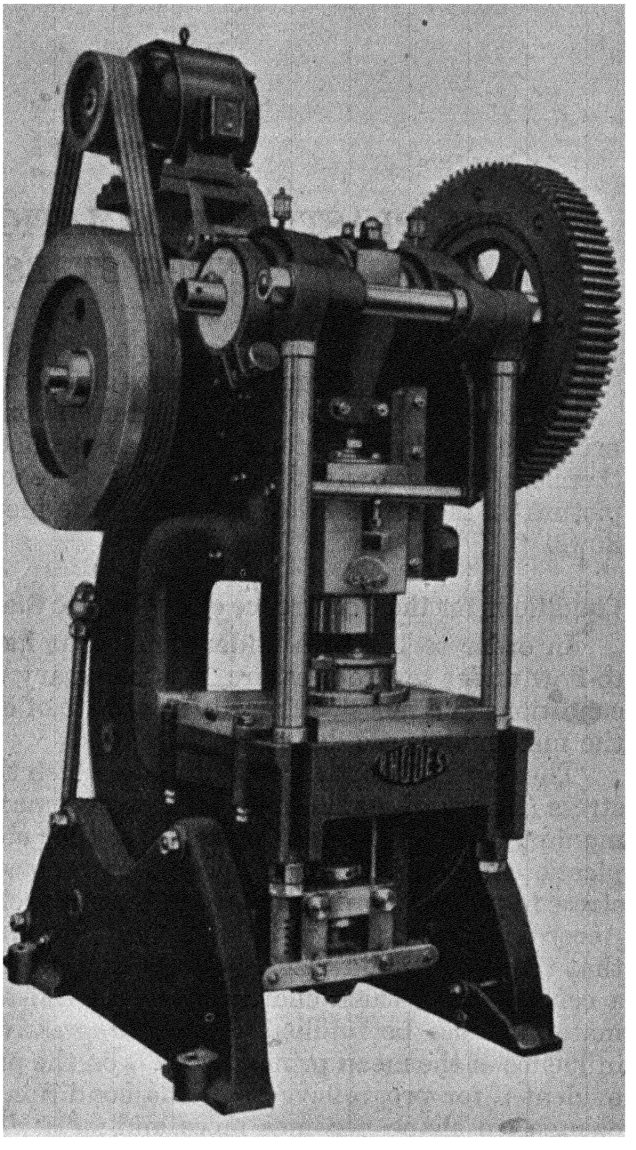


Fig. 13—THE "SIMPLEX" DEVICE FITTED TO THE RHODES NO. B3½ OPEN-FRONTED PRESS, MAKING IT SUITABLE FOR GENERAL BLANKING, PIERCING, BENDING, AND DEEP DRAWING

Chapter VI

THE PLASTIC DEFORMATION OF METALS UNDER STRESS

THE industrial use of metallic materials depends very largely on their capacity for undergoing changes of shape and suffering severe plastic deformation without loss of internal cohesion. An insight into the processes of plastic deformation and deduction of the laws governing them can only be arrived at by getting, for each individual process, a clear picture of the stress relations and of the manner in which the material flows.

Conditions for the Occurrence of the Plastic State

In order to begin to understand what happens when a metal starts to flow under severe pressure, it is necessary to have a clear grasp of the conditions in a metal, primarily in a state of elastic stress, which occur at the moment plastic deformation occurs.

The original theories, according to which the exceeding of a maximum stress (theory of maximum stress) or of a maximum extension (theory of maximum strain) is essential in order that either fracture takes place or plastic deformation begins, have been replaced by the maximum shear-stress hypothesis, owing mainly to the researches of English investigators. According to this theory, in order that flow may commence, the condition that the greatest difference between the principal stresses should exceed a certain limit which characterises the resistance to deformation of the material must be fulfilled. With progressive plastic deformation, the influence of the mean principal stress on the process of flow is increasingly evident : for progressive flow, the condition of constant energy due to changes in shape becomes more and more determinative : according to this the sum of the squares of the principal shear stresses is given by the square of the yield stress under purely tensile conditions.

Owing to the extensive development of the theory of elasticity, we know, in many cases, the state of stress in metals under purely elastic influences. But as regards the plastic state our knowledge is inadequate and there is no corresponding mathematical treatment possible. But certain deductions from the distribution of stress under purely elastic conditions are applicable to those for flow and especially for the stress relations which determine the occurrence of plasticity. These deductions

Fig. 1.—LUDERS LINES OR STRETCHER-STRAINS

are often profitable. Extremely illuminating results throwing light on what happens in the first stages of deformation have been obtained by examining the slip that occurs in certain layers of the metal. When mild steel is subjected to tensile stress and passes the yield point, what are known as " flow lines " or Luders lines appear. A typical picture of these markings is shown in Fig. 1.

Movement within the Metal

Close examination of these lines reveals that they are the intersections of the flow surfaces with the surface, inclined at an angle of approximately 45 degrees to the axis of the test piece of metal. They are the surfaces of maximum shear stress along which the portions of the test piece mutually move against each other. This formation of flow lines in mild steel is due to the sharp demarcation of the flow range at the yield point for the material clearly shown in the tensile-stress diagram.

In Fig. 2 stress-strain curves of this type are shown alongside of the normal curve *a*, which applies to copper, for example. Within the horizontal range of flow shown in the diagram, and especially at the sudden decrease of stress from the upper yield point S_0 in Fig. 2*c*, there

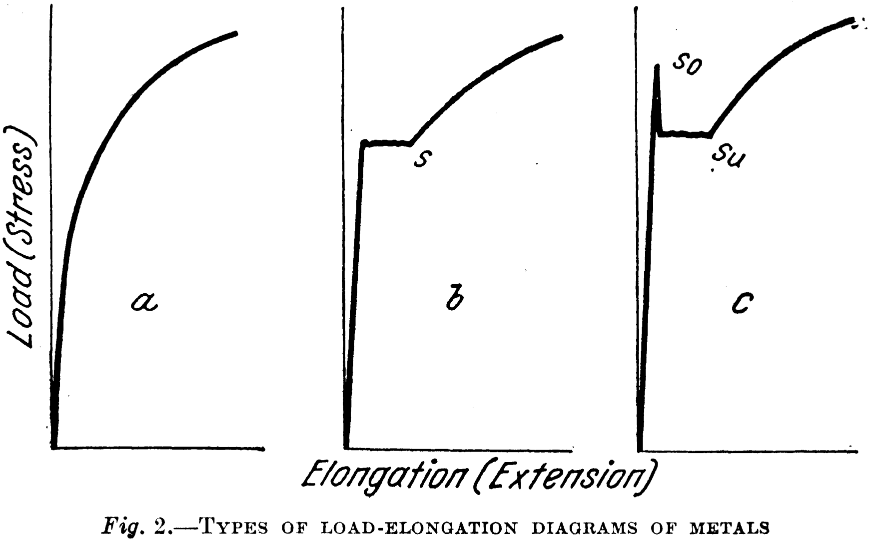


Fig. 2.—TYPES OF LOAD-ELONGATION DIAGRAMS OF METALS

appear on the test piece, either singly or in groups, these sharply defined flow lines which gradually spread over the entire length with progressive extension within the same range.

The course of these flow lines is closely related to the stresses within the metal, and, by means of an etching process which has been developed by Fry and others, involving the use of acid cupric chloride, it is possible to make the flow surfaces within the metal visible.

Path of the Flow Surfaces

The path of the flow surfaces within the metal correspond, to a great extent, with what we should expect on the basis of our very limited knowledge of the laws of plastic deformation. The flow-line system sketched in Fig. 3 corresponds to the theoretical requirements in the case of a prismatic test piece which has been pressed on both sides beyond the yield point by means of narrow-faced tools.

From the corners of the tool the work is penetrated by two groups of flow surfaces which cut one another mutually at right angles, and within the same group are so joined that the angle which they form with one another at the intersections with a flow surface of the other group remains constant. Figs. *b*, *c*, and *d* illustrate how the flow lines penetrate deeper and deeper into the metal as the pressure increases ; the average compressive stress changes as a flow line is traversed proportionally to the angle through which its tangent rotates. The shading in Fig. 3*d* is in-

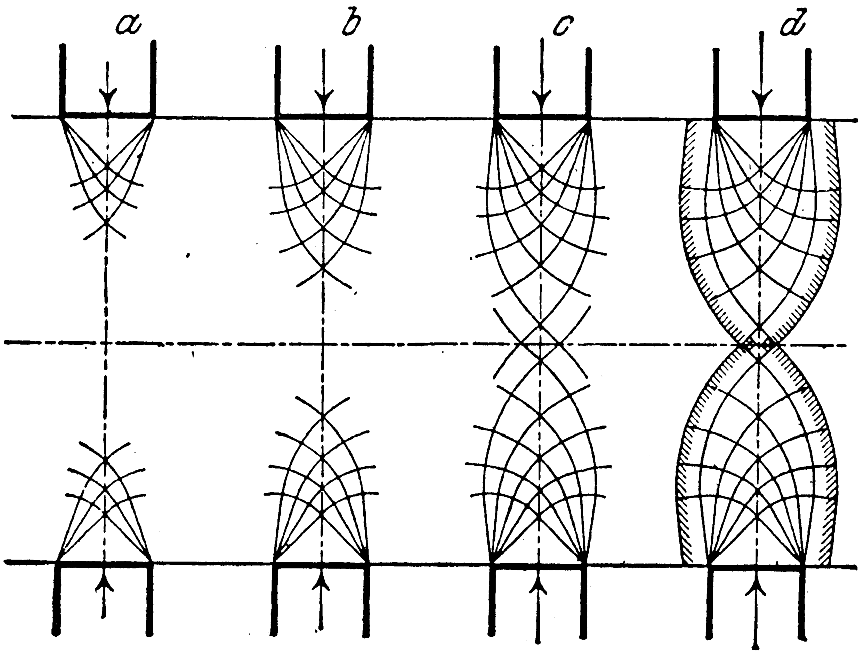


Fig. 3.—THEORETICAL COURSE OF THE FLOW SURFACES

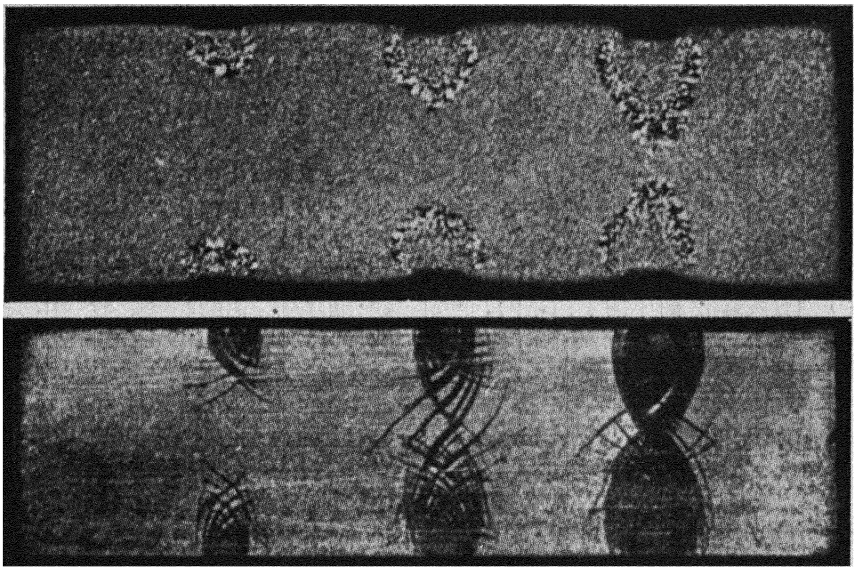


Fig. 4.—FORMATION OF SLIP LINES DURING THE WORKING OF MILD STEEL WITH NARROW-FACED TOOLS

tended to show that with heavy pressure within this region the material starts to become completely plastic. Single lines of flow can then no longer be recognised.

Fig. 4, which is a longitudinal section of the test piece, shows that the flow-line system which has been drawn correctly represents the stress relations which actually exist and the plastic displacements which result.

Etching by Fry's method has made visible the flow lines, which are found deeper and deeper as the pressure increases. At the smallest pressure the flow lines do not penetrate to the centre.

This dependence of the degree of plastic deformation on pressure may be looked at in another way. Mild steel has the peculiar property of undergoing coarse recrystallisation following critical extension and annealing. If it is cold-worked until it has undergone 5–20 per cent. reduction in area and is then annealed from 700°–900° C., very coarse crystal growth takes place. Under an irregular stress such as exists on pressing between narrow hammer faces, the portions of the steel which are stressed within the specified critical limits stand out clearly against the more strongly and less strongly deformed regions which have a fine-grained structure. This is seen in the upper part of Fig. 4.

Let us look at what a similar investigation along these lines shows in the case of rolling mild steel. This is extremely important from the practical point of view, for the various grades of mild-steel plate which are dealt with elsewhere are probably the most important of press materials.

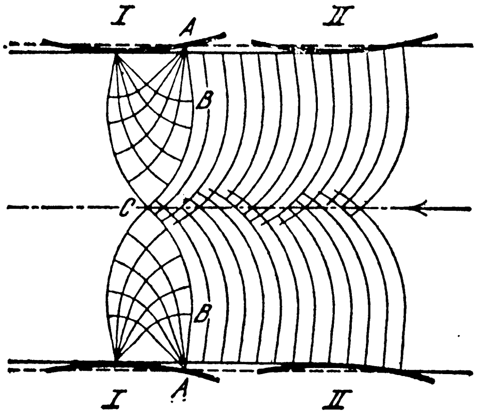


Fig. 5.—Arrangement of flow surfaces in rolling

The Effect of Rolling

The rolls of a rolling mill can be looked upon as press faces, bearing always in mind that the speed of compression is not the same for all points of the contact surface between the rolls and the material. What stresses are involved are shown in Fig. 5.

The speed of compression falls from a maximum at the point A, where the material enters, to zero where it leaves in the plane of the rolls. If this is so, the flow surfaces originating at the first point of contact of rolls and material would be expected to be especially well defined.

Fig. 6 shows the flow lines which occur on cold rolling mild steel with small reduction. The only flow lines which occur are those which are to be expected, namely, those which occur at the entrance of the material into the rolls.

In view of the importance of mild steel in press-shop work, it is important to appreciate what happens when mild steel is rolled, although, of course, we are here considering the matter from the point of view of plastic deformation. The ratio between the thickness of the material which is being rolled and the roll diameter, as well as the reduction in thickness, are vitally important. Roll diameter and relative reduction must be made large enough so that the effect completely penetrates the material. If this does not occur, there will be an undeformed inner zone in which longitudinal tensile stress exists.

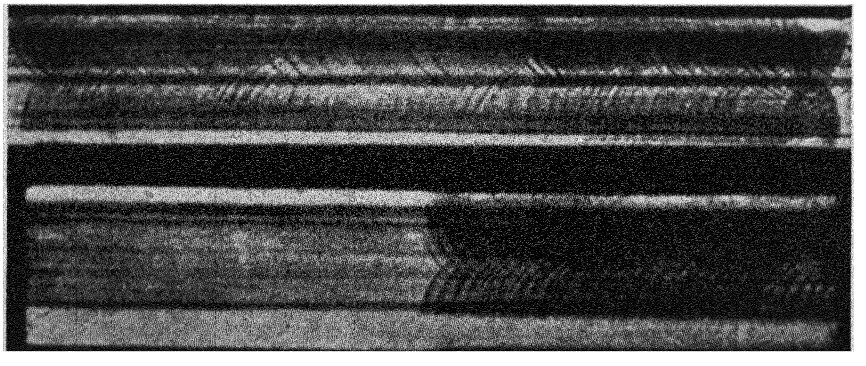


Fig. 6.—Formation of slip lines in cold rolling

Flow during Transverse Compression

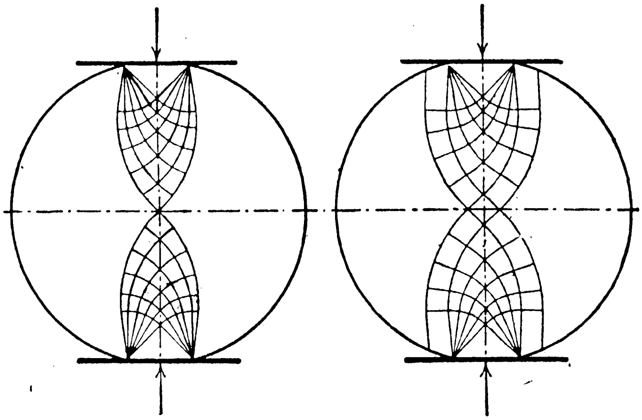


Fig. 7.—FLOW SURFACES FORMED DURING TRANSVERSE COMPRESSION OF CYLINDERS

Again the close resemblance between the theoretical stresses postulated and those actually realised are seen in the illustrations, which show the flow surfaces during the transverse compression of cylindrical-shaped metal bodies. Fig. 7 shows the flow lines to be expected and Fig. 8 fully confirms the prediction. Only the region of the sample between the press faces is affected by the deformation, and this only reaches the centre when the pressure is heavy.

The Mechanism of Deformation

In these examples, which are taken as a means of studying the beginnings of plastic deformation and its early progress, the change of

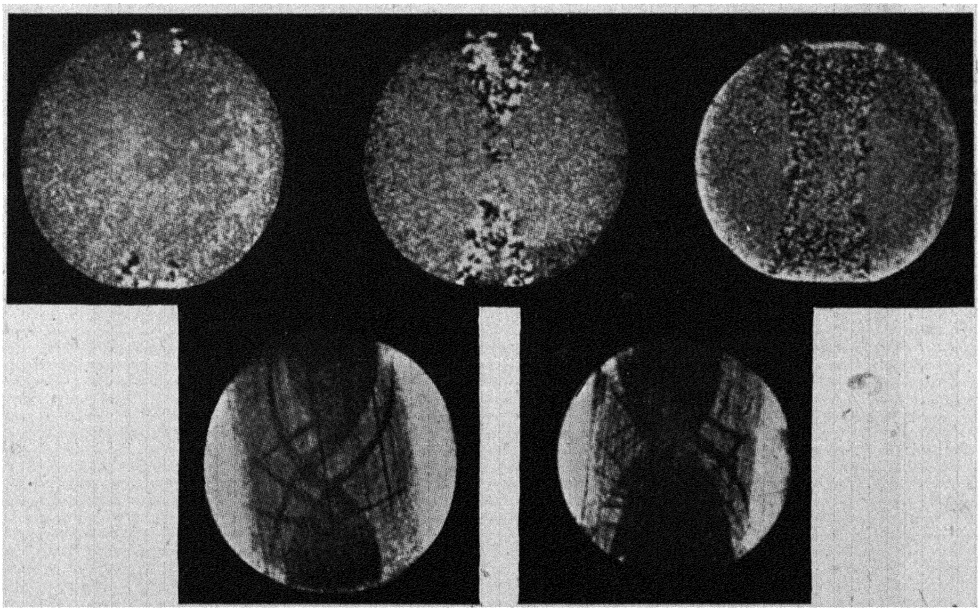
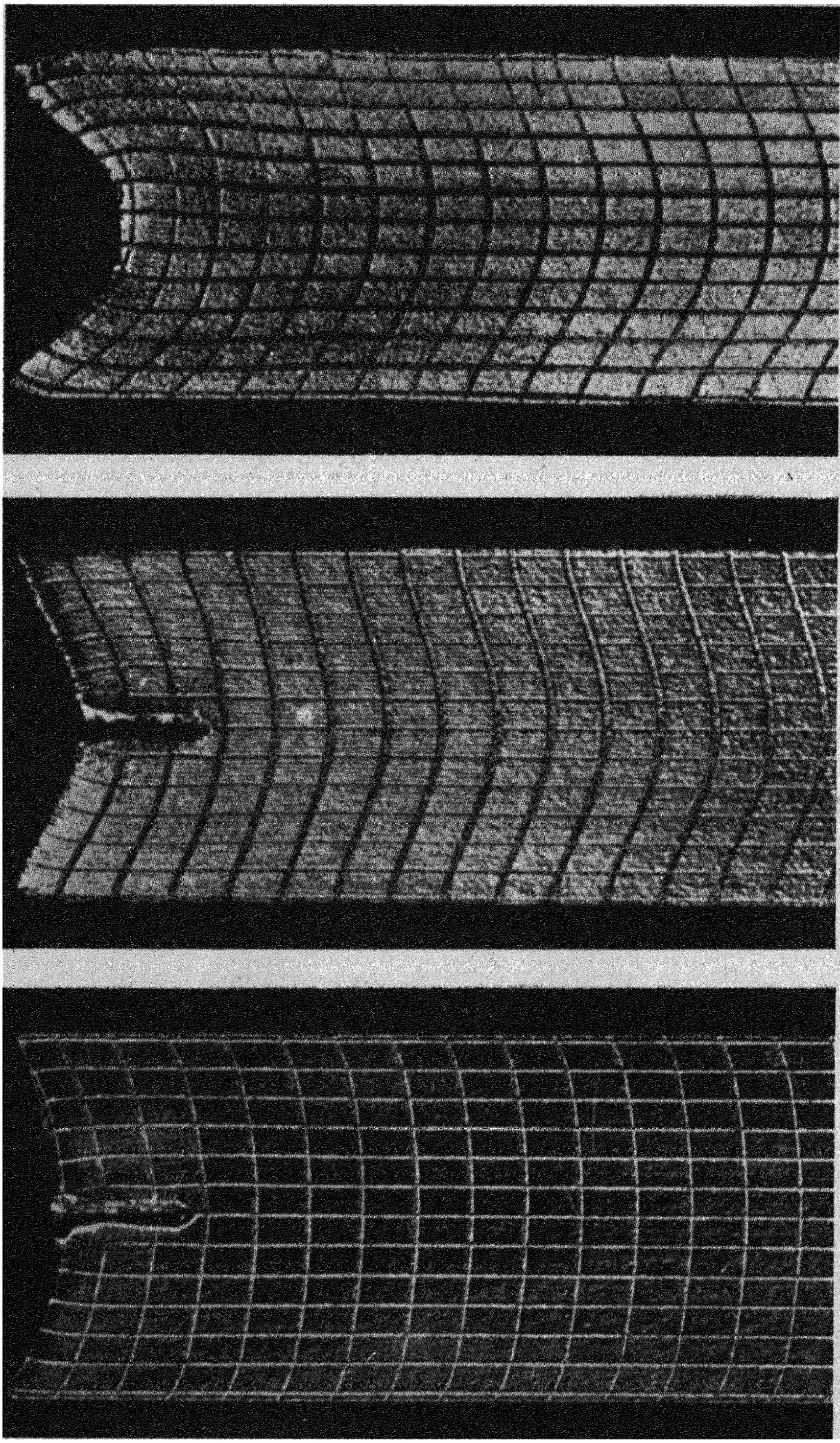


Fig. 8.—FORMATION OF FLOW LINES DURING THE TRANSVERSE COMPRESSION OF STEEL CYLINDERS



40° 24° 12°

Fig. 9.—Drawing tests with reduction 36·2 per cent.

shape is small. In fact, the alterations in shape are so small that there is really no sensible change in form from the original.

It has long been known that plastic deformation is a complicated process, and if, in comparing the initial and final dimensions of a stressed piece of metal, we act on the assumption that the change in shape is the result of deformation on simple square lines, then obviously we are making a mere rough approximation to serve as a starting-point.

It is impossible to overlook the fact that in a piece of metal under severe stress, mutual displacements occur in the planes between the individual layers owing to active shear stresses and they modify the simple conception of deformation.

For the accurate investigation of what occurs in the body of the metal during forming, drawing, extrusion, rolling, and piercing, test pieces of metal have been cut longitudinally and one of the cut surfaces divided into a series of squares. No shear stresses can arise on the dividing plane and when drawn such pieces behave as though they were uncut. Fig. 9 shows such a test piece, $\frac{13}{16}$ths in diameter, drawn through a conical die with angles of 12, 24, and 40, the reduction being 36 per cent.

It is obvious that only the squares in the centre remain rectangular in shape, those at the side being distorted into parallelograms. Only in the centre does the deformation correspond to simple elongation. As the centre recedes, additional slip occurs, increasing as the angle of the die increases.

Grain Size and its Significance

The literature of metals through the past few years contains an increasing number of papers on grain size by scientists, and from the obvious, meaning of the phrase the importance of this aspect of metallurgy—since it has to do with the "grain" of the sheet metal which is the raw material used in the press shop—is apparent to all those who have to see that expensive presses and skilled labour give their maximum

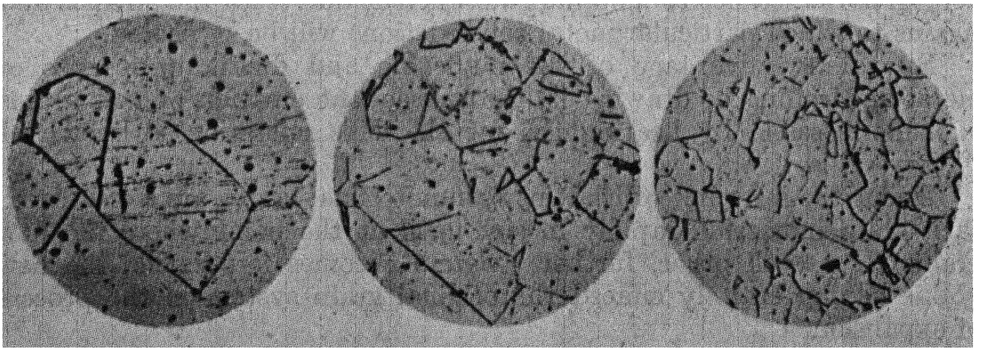


Fig. 10.—Decreasing grain size in Monel metal

output of well-finished goods. For however suitable the press and however skilled the workman, if the "grain" of the metal is unsuitable the percentage of failures and hence production costs will rise sharply.

The phrase "grain size" is in itself so descriptive that it might be objected that to qualify it will detract from its clear and obvious meaning. That would be quite true if the variations throughout the mass of the various crystals were negligibly small. But obviously if we are dealing with a long, thin hexagonal crystal, it will look entirely different and give a different grain size if we examine along the length or across the short axis of the structure. In other words, how can the real value numerically of the crystal size be assessed unless we are cutting through the metal in a known direction?—known, that is, as far as the crystal orientation is concerned. The metallurgist takes a small piece of metal which he hopes is representative and cuts it, polishes and etches it, and looks at it under the microscope.

When magnified, the metal is seen as a substance made up of a multitude of small particles or "grains." These grains possess none of the characteristics of, for instance, sugar, or of cereal grains such as wheat. Neither of these latter have the slightest tendency to coalesce, and both sugar and wheat will subdivide easily under pressure into powder form—in the case of wheat into flour. Metal grains are almost universally tensile, and have extremely strong reciprocal attractive properties, considerable force being needed to separate them. The grain structure of most metals is quite invisible to the human eye, and can only be seen to advantage with the aid of a microscope after the metal has been etched. In rare instances grain size may be observed by the unassisted eye in a piece of well-burnished metal like brass, but such cases are exceptional.

Mechanical working and heat treatment are directly responsible for the grain size in a metal, the general rule being that the tougher and stronger the metal, the finer the grain. The knowledge that grain size has a direct bearing on the degrees of hardness and strength in a metal has been of very great assistance to metallurgists when dealing with the stresses and strains to which particular metal constructions will be subjected.

By taking advantage of the malleable and ductile properties of metal and rolling or drawing it, the subsequent creation of new grains is made possible by heating the metal. This operation is known as "recrystallisation."

Under the influence of heat, new, infinitesimal grains are engendered, each grain increasing rapidly in size until at the point where the new grains meet each other, further progress becomes impossible, the new grains having entirely effaced the original grain system in the process of expansion.

But only a few of the crystals seen by the metallurgist under the microscope will show the average geometric section, for it is known that

when a metal exhibits definite orientation, the microstructure will appear very different in one section from its appearance when the specimen is turned through 90 degrees. All of which brings out the obvious objection, "Is not orientation of the crystals, the way they lie, surface to surface, more important?" In the light of these obvious objections, is there any real meaning in this seemingly illuminating property of sheet metal? Is grain size a definite physical property with a clear, unambiguous meaning, or is it just another misleading phrase?

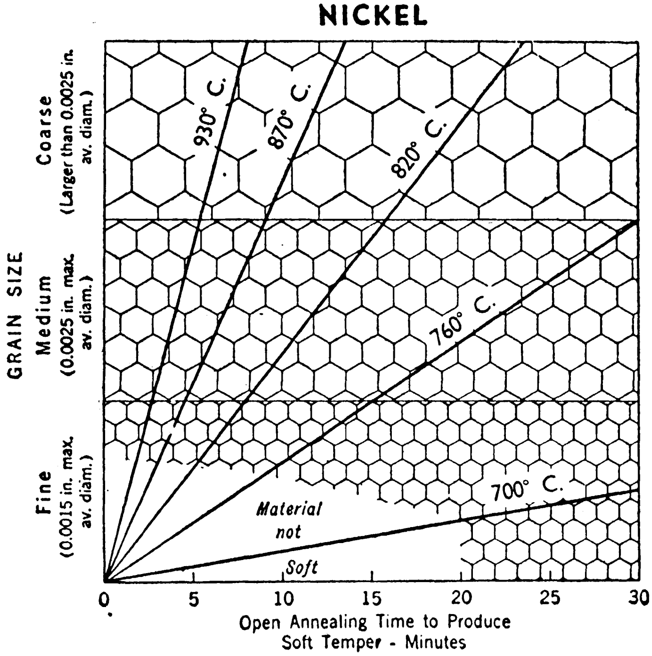


Fig. 11.—INCREASE IN GRAIN SIZE IN NICKEL WITH VARIOUS ANNEALING TIMES

Practical Significance of Grain Size

The answer to this is that grain size, if these obvious limitations and qualifications are kept in mind, is of real value to the practical man. It does undoubtedly give a clue to the behaviour of sheet metal not only when being severely deformed under the press but in all other related operations.

It is all a matter of practice. It is common knowledge that a worker acquires, through handling metals over the years, an indefinable "feel" for them, and slight shades of difference in appearance at various stages and in various states will tell him much which is hard to define precisely, but which is nevertheless quite real. It is not exactly the same with "average grain size," but the analogy is sound. The only way for using the microstructure practically is to have as a standard of reference pictures which are "typical" of what is good "average grain size." By referring the metal whose qualities it is desired to assess to them, it will be found that a definite standard emerges which is of great value.

Given the necessary apparatus, the pictures are comparatively easy to prepare. Their interpretation is all the press worker is concerned with, and he will at once begin to make a mental note of the *regularity*

of the picture. A mental image will be formed of the " average " crystal and an estimation immediately made as to the number of crystals appreciably bigger and appreciably smaller than the " average."

To be more concrete, the following points should be kept in mind :

(1) In our present state of knowledge, no hard-and-fast rules can be given as to the best average grain size for various metals and alloys. The type of operation, degree of deformation, and depth of draw will qualify the needs, and if the microstructure of the metal is to be of practical value the picture must always be correlated with a definite set of operations.

(2) Severe distortion will always call for a smaller average grain size than an operation such as light pressing or drawing.

(3) Large " average grain size " is to be avoided where appearance of the finished work is important, for it makes for roughness, and polishing costs may be prohibitive.

(4) A large grain size will often permit of work being deformed to the required extent in one operation whereas sheet with a smaller value will need to be pressed or drawn in two or three operations, with inter-stage annealing. Obviously (3) and (4) must be balanced against each other in assessing production costs and the question determined in the first place by trial and error.

(5) A larger grain size is permissible in dealing with heavier gauges of sheet metal, and it is a well-known fact that the heavier sheet adapts itself better to the internal stresses involved.

(6) Regularity of the microstructure is important. If there are too many fine crystals the ductility of the sheet is impaired, and if there are too many large crystals there is likely to be trouble in the appearance of the finished work, and it will have low tenacity.

Annealing and Recrystallisation

By annealing at a suitable temperature, which varies with the metal, the fibrous grain structure which results from a greater or lesser degree of cold working can be converted into an equiaxial and uniform one, although the grains may remain elongated if resistance to the normal formation of new crystals is obstructed by the presence of heterogeneous inclusions in considerable amount.

In every case a definite period of time and a temperature, specific for the metal, are required in order to enable this recrystallisation to take place. The lowest temperature required for a given metal in a given condition to recrystallise is termed the *recrystallisation limit.* The actual time required for annealing is fixed in production technique by what is economically a sound value and varies from a day on the one hand to a quarter of an hour on the other, and with this constant period for annealing, for all metals and alloys, the extent of the deformation to which the material has been subjected governs the recrystallisation limit. With

decrease in the degree of stress in the regions of high reductions, there is gradual, but only gradual, decrease in the recrystallisation limit. Where, however, the deformation is of the order of 10 to 0 per cent. reduction, the limit increases quickly with decreasing deformation. Within a definite annealing time, no recrystallisation takes place if the reduction is below a certain limit, even though the temperature be maintained slightly above the melting-point. In the case of steel, recrystallisation takes place below the transformation temperature only when the reduction exceeds 3 per cent. Above the transformation range of steel, a different phenomenon occurs and grain refining instead of recrystallisation takes place.

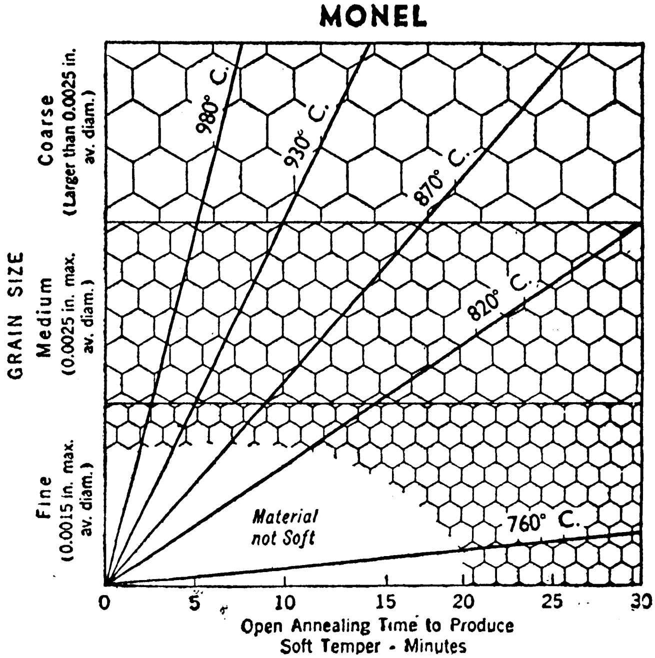


Fig. 12.—INFLUENCE OF ANNEALING ON GRAIN SIZE OF MONEL METAL

Factors Influencing Recrystallisation

Broadly speaking, the grain size in a metal or alloy resulting from complete recrystallisation depends upon a number of factors which can be conveniently summarised as follows :

(*a*) The smaller the degree of previous deformation, the larger the average grain size.

(*b*) In their effects there is great similarity in the end result of different processes of working.

(*c*) The greater the temperature at which annealing is carried out, the larger becomes the average grain size.

(*d*) Grain size increases with increasing time of annealing.

(*e*) Increasing the time of annealing from between two to three times, is the same as increasing the temperature of annealing by 10° C.

(*f*) Speed of heating to the required annealing temperature is important in some metals. Aluminium, a particularly good example, shows a much-increased grain size when the rise is gradual.

(*h*) The larger the initial grain size before working, the larger the

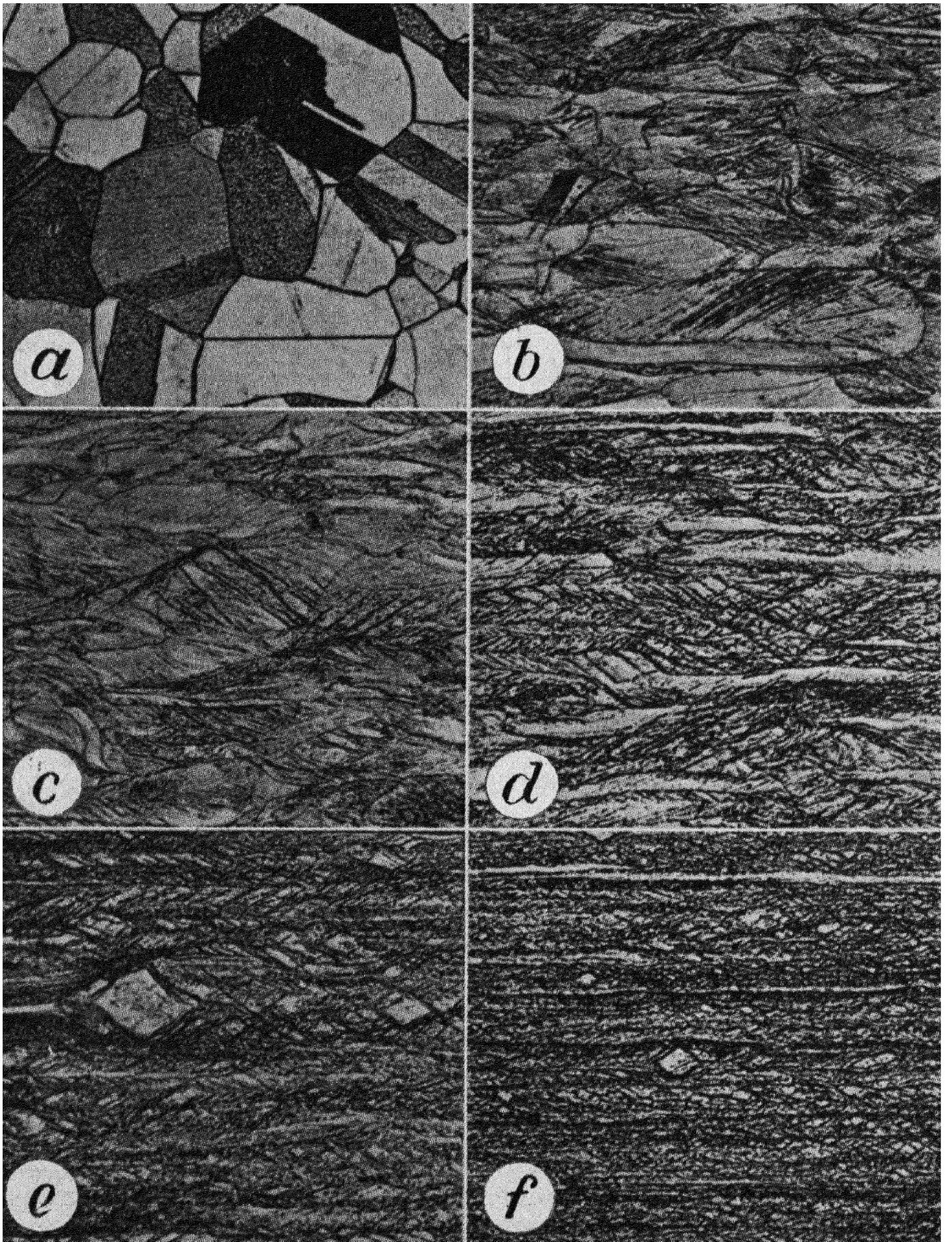


Fig. 13.—MICROSTRUCTURE OF 70 : 30 BRASS WITH PROGRESSIVE ROLLING

grain size after recrystallisation. Large original grain size offsets a lesser extent of previous cold reduction.

The grain size of many recrystallised metals does not depend, within certain limits, upon the degree of temperature of the previous deformation, but in the case of aluminium and its alloys the grain size of the recrystallised metal increases if the deformation temperature is high and the rate of loading is slow. The grain of hot worked steel and copper, after recrystallisation, is refined by increasing the rate of working.

Effect of Slight Variations in Chemical Composition

As the result of a large number of investigations, grain sizes for a great variety of metals and alloys have been determined after different reductions and annealing treatments and recrystallisation diagrams established. These three-dimensional diagrams have only a limited practical value, as the actual grain size is appreciably affected by other factors, notably slight variations in chemical composition. The effect of chromium on brass is interesting and illustrative.

Small amounts of chromium are exceptionally effective in retarding grain growth in 70 : 30 brass, even at 850° C., and although the annealing range may vary widely there is far greater uniformity in grain size than is seen when chromium is not present. There is a slight loss in ductility, but this loss is more than compensated for by the grain size and increased hardness.

Only about 0·05 to 0·06 per cent. of chromium is needed to give a grain size below 0·02 mm. : about 0·10 per cent. holds it below 0·04 mm. when the annealing temperature is as high as 750° C., and 0·17 per cent. is entirely effective when annealing is done at 850° C.

As to the effect of the addition of chromium on the deep-drawing qualities, cup tests show that a slightly increased stress is necessary to effect rupture, but the chromium-treated metal does not enable quite such deep draws to be made as with the metal itself, without the addition of chromium. But, as has been said, this is more than offset by the uniformity and low grain size. For equal grain size, approximately equal depth of draw is obtained, but with greater tensile strength. There is the additional advantage that because of the wide temperature range over which the grain size remains practically unchanged, drawing behaviour is readily controlled.

Crystal Structure in 70 : 30 Brass with Increased Reduction

In Fig. 13 are shown typical microphotographs of the changes in structure on rolling 70 : 30 brass. The structure before rolling is shown in *a*. A reduction in thickness of 10 per cent. showed strain lines in isolated crystals, particularly near grain boundaries (seen in *b*). With increasing rolling reductions, there is evident increase in the extent of the strain markings, and where reductions are of the order of 40 to 50

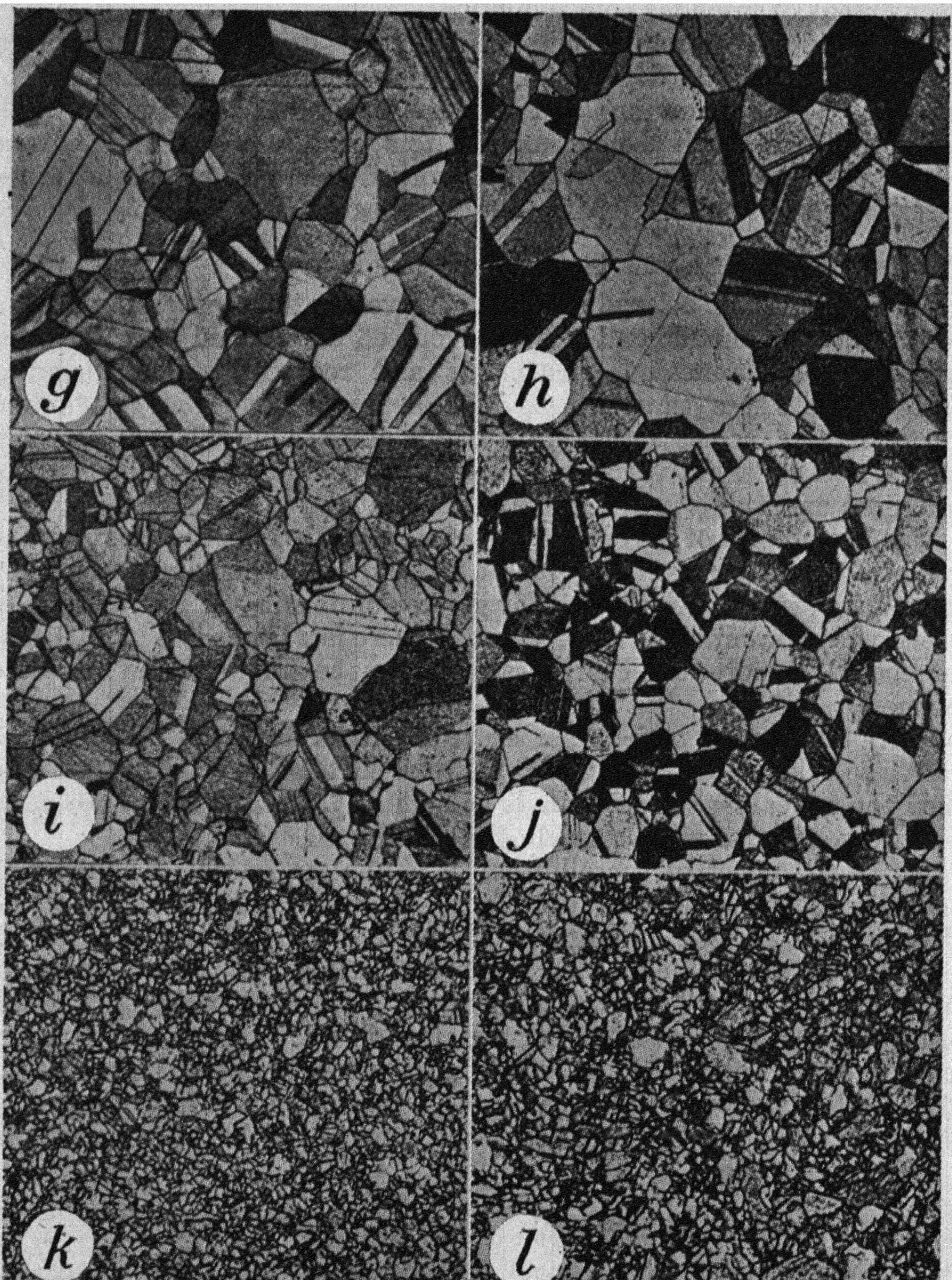


Fig. 14.—MICROSTRUCTURE OF 70 : 30 BRASS WITH PROGRESSIVE ELONGATION AND INTER-STAGE ANNEALING

per cent., practically every crystal shows such marking. The lines, it will be seen, are parallel to each other within individual crystals, but do not appear to have any particular orientation with respect to the rolling direction.

As the rolling proceeds, the crystals begin to be broken by strain markings, and these definitely have orientation, being approximately transverse to the rolling direction and inclined to the strip surface at an angle of approximately 35 degrees. In *d* it will be seen that the markings appear across nearly all the grains and often in two supplementary directions, giving rise to a criss-cross appearance. In spite of the break-up of the crystals during reductions from 50 to 70 per cent., the original crystal structure can still be recognised. But in *f*, where the reduction is 80 per cent., orientation is becoming evident, there being, with the break-up of the crystals, discrete fragments with their axes transverse to the rolling direction.

Reduction and Inter-stage Annealing in 70 : 30 Brass

In Table I are given the grain sizes observed in 70 : 30 brass strip, with different reductions and subsequent annealing at 400, 500, 575, 700, and 800.

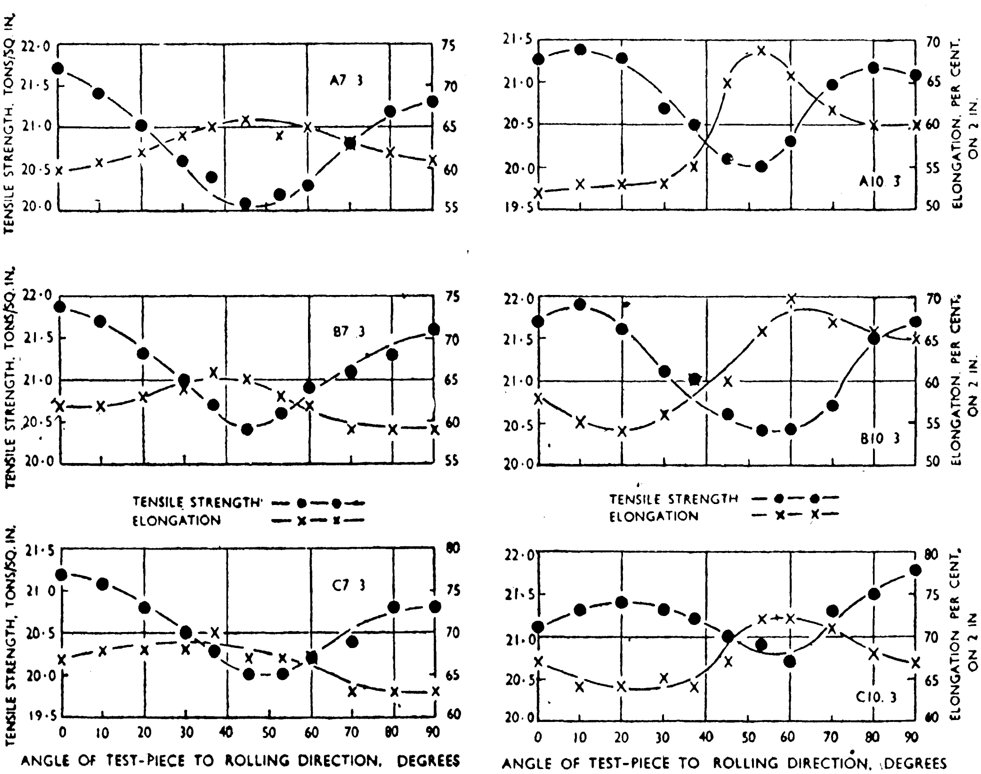


Fig. 15.—GRAIN SIZE AND MECHANICAL PROPERTIES

TABLE I.—AVERAGE GRAIN SIZE OF ANNEALED STRIPS (IN MM.) OF 70 : 30 BRASS

Nominal Cold-rolling Reduction, per cent.	Series A					Series B					Series C				
	Final Annealing Temperature, ° C.					*Final Annealing Temperature, ° C.*					*Final Annealing Temperature, ° C.*				
	(1) 400	(2) 500	(3) 575	(4) 700	(5) 800	(1) 400	(2) 500	(3) 575	(4) 700	(5) 800	(1) 400	(2) 500	(3) 575	(4) 700	(5) 800
(1) 10	0·012	0·03	0·05	0·2	0·3–0·35	0·015	0·04	0·05	0·2	0·5	0·03	0·05	0·065	0·2	0·3
(2) 20	0·009	0·03	0·06	0·2	0·3	0·012	0·035–0·04	0·05–0·055	0·2	0·4	0·025	0·035	0·06	0·2	0·35
(3) 30	0·007	0·035	0·05	0·2	0·4	0·010	0·035	0·055	0·15–0·2	0·4	0·02	0·03	0·065	0 2	0·35
(4) 40	0·006	0·035	0·055	0·15–0·2	0·4	0·009	0·03–0·035	0·05–0·055	0·15–0·2	0·4	0·15–0·02	0·035	0·07	0·2	0·3
(5) 50	0·006	0·04	0·05	0·15–0·2	0·4	0·008	0·035	0·055–0·06	0·15–0·2	0·45	0·015	0·03	0·07	0·15–0·2	0·3
(6) 60	0·005	0·035	0·05	0·15–0·2	0·35	0·007	0·03–0·035	0·055–0·06	0·15–0·2	0·35	0·012	0·035	0·065	0·15–0·2	0·3
(7) 70	0·004	0·03	0·055	0·15	0·35	0·006	0·03–0·035	0·05–0·055	0·15	0·4	0·010	0·03	0·065	0·15	0·35
(8) 80	0·0035	0·03	0·05	0·15	0·3	0·005	0·03–0·035	0·055	0·15	0·35	0·008	0·035	0·06	0·15	0·35
(9) 90	0·0035	0·035	0·05	0·15	0·3–0·35	0·004	0·03–0·035	0·05	0·15	0·3	0·007	0·035	0·06	0·15	0·35
(10) 95	0·0035	0·035	0·055	0·15	0·35	0·004	0·035–0·04	0·05–0·055	0·1–0·15	0·3	0·006	0·03	0·06	0·15	0·35

The grain size of strips annealed at 400° C. decreases with increasing reduction irrespective of the initial grain size, before final rolling. The degree of uniformity of grain size in the finally annealed strip is affected by the initial grain size, and by the rolling and annealing conditions, particularly when the final rolling is limited by reductions up to about 40 per cent. Examples illustrative are shown in Fig. 14. When the final annealing is far removed from the penultimate anneal, the resulting structure is irregular, as is evident from *g* and *h*. But when the two temperatures are identical, a high degree of uniformity is obtained, as is seen in *k* and *l*.

The curves in Fig. 15 show the effect on tensile properties in the case of three different brass strips. These were rolled with a reduction of 95 per cent. and show that the tensile-strength values are at a maximum and the elongation values at a minimum at about 10–20 and at about 90 to the rolling direction, while the tensile-strength values are at a minimum and elongation at a maximum at about 55 to the rolling direction.

Chapter VII

DRAWING AND PRESSING PERFORMANCE OF VARIOUS SHEET METALS

Steel Sheet for Pressing and Deep Drawing

POWER-PRESS users have no standard specifications by which to judge the pressing and deep-drawing properties of the sheet steel and strip supplied to them. At the best, all they can do, having found a source of supply which suits a particular operation, is to adhere to this source. The usual industrial grading is based on the treatment given after the metal has been hot rolled, though even these grades vary from one producer to another, since no two costly sheet-steel plants are the same, and not only will the sequence of operations to which the metal is subjected—cold-rolling, annealing and pickling, etc.—vary in sequence but also in degree. More important still, rolling mills often obtain not only their billets, but also slabs from various casters, and thus have not under their own control the fundamentally important processes which have such a profound influence on the steel's ultimate behaviour under the press. And here chemical specifications cannot help. For the carbon content of the sheet and strip used lies between the limits of 0·05 and 0·11 per cent., whilst an average figure for the presence of certain objectionable impurities can be very misleading, since it assumes even distribution throughout the mass and ignores the fact that segregation or the localised concentration of the impurities is of the greatest importance, and of this chemical analysis gives no information.

Pickled, Close-annealed Steel

P.CA. is practically the cheapest grade used for pressing and deep-drawing work. The surface is rough owing to the fact that it is pickled after being hot-rolled. But apart from this surface pitting, due to the removal of scale which has been rolled in during the hot-rolling treatment, it tends to give a coarse surface on deep drawings. The unevenness of the crystal size of the metal is responsible for this, and it is frequently abnormally large. Microscopic examination reveals this very clearly. Low tenacity is also a consequence of this, and accounts for failures when this grade is too freely used and worked beyond its limits.

Pickled, Cold-rolled, Close-annealed

As compared with P.CA. grade, this has a bright smooth finish and greater uniformity in thickness, both due to the cold-rolling and the ter-

minal close-annealing which restores the ductility of the metal. But the crystal structure remains essentially the same in the body of the metal because the cold-reduction is too slight to affect any refining of the crystal grain.

P.CR.CA. may or may not have received a " pinch-pass " to obviate stretcher-strain markings after going through the press. This grade has wide applications for deep-drawing and pressing work in which the deformation is not unduly severe.

Full-finished Sheet

This grade N.P.CR.CA.CR. is used for deep drawing, and particularly in the pressing of motor-car body work. It is normalised, pickled, cold-rolled, close-annealed, and cold-rolled again. The important distinction between it and the two previous grades lies in the refining of the crystal structure of the metal, which takes place under the influence of the preliminary normalising process and the reduction in the internal stresses in the sheet in different directions relative to that of rolling. The first cold-rolling is to produce a good surface and the final rolling, relatively light, obviates stretcher-strain markings appearing later. In this grade the deep drawing and pressing properties are greatly increased. There is, it is true, a slight reduction in ductility, due to the final cold-rolling, but this is entirely outweighed by the softening due to final annealing and to the refinement of the crystal-grain structure in the normalising process.

Extra Full-finished

A further refinement of the last grade is made from steel with an especially low content of carbon, manganese, sulphur, and phosphorus. It is relatively expensive, since it is made from selected portions of selected ingots. Its performance is excellent, and it represents the highest type of sheet steel available for deep drawing and pressing. The increased cost is offset to a certain extent by a reduction in the number of inter-stage annealings, and its selection is often indicated when it is necessary to cut out inter-stage annealing.

Extra full-finished sheet is available in a number of proprietary lines, supplied by various makers ; as has been said, it is the highest quality available where ductility up to the maximum is required to produce some particularly intricate contour.

Normalised Sheet

Provided the carbon content is low, a normalised sheet will always behave better under the press than one which has been close-annealed. The grain or crystal structure is undoubtedly more regular and it is generally finer. The difference in appearance under the microscope between a

normalised and a close-annealed steel is very striking. The close-annealed will show the particles of pearlite (iron carbide and ferrite) running in long streaks or stringers, whilst in the normalised metal they have a close, tight compact, and even structure. Heavy cold working of sheet steel prior to annealing does much to lessen the microstructural difference between annealed and normalised metal, but in the main it is true to say that when buying in the market the normalised sheet can be counted upon to be the better and more uniform.

Open-hearth Steel

The bulk of steel used for pressing and drawing is made by the basic hearth process which reduces to a minimum the content of phosphorus an element which hardens and impairs the ductility of the metal. This is of great importance from the press-shop point of view. Sulphur is also removed, not only during the " boil " on the hearth, when carbon monoxide is being freely evolved and is oxidising or " killing " carbon and phosphorus, but also by manganese added to the mixer. Bessemer steel, made by an acid as contrasted with a basic process, is less ductile than basic hearth steel and gives a sheet metal which is more prone to show such defects as stretcher-strain markings, blue-brittleness, and strain ageing. But for shallow drawings or pressings, where rigidity is a very important factor, as in car bodies, Bessemer sheet has extra stiffness and rigidity, which is very desirable.

But those are the best qualities of Bessemer steel, for an open-hearth steel does not work-harden to anything like the same extent under the press, and is capable of giving considerably deeper draws.

" Killed " and Semi-killed Steels

The press-tool production engineer should be aware of the further difference between " killed " and " rimming " steels. The difference can be very simply stated. A rimming steel still has life in it when it is poured into the ingot mould. Carbon monoxide gas is still being given off and rises to the surface. As the mould cools, the metal subsides and solidifies from the outside. A " killed " steel solidifies quietly without effervescence. It forms no rim at the top. From the press-shop point of view the difference is important. In the first place, the sheet-metal manufacturer can make a higher percentage of his rimming steel into plate or strip than when working up a killed ingot. Secondly, and this is really the important difference from the present point of view, which concerns performance under the press, a rimming steel consists of an outer skin of nearly pure iron or ferrite enclosing a core of iron in which the impurities are evenly dispersed : a " killed " steel ingot has no such surface skin of pure iron or ferrite, and the larger core or pipe, which is cropped off prior to rolling into sheet, contains most of the slag impurities. In effect this means that a

rimming steel, because of the ferrite or pure iron skin, gives a better surface finish, and what is more, this surface skin, since it is homogeneous, is less likely to show surface blemishes and inequalities than a sheet made from killed steel, when it goes under the press.

A killed steel and a rimming steel, both from the same melt, both rolled into sheet under precisely the same conditions, show marked difference in structure, the first being the finer.

Aluminium

The presses required for drawing aluminium are the same as those used in the drawing of other metals. The size and capacity of the machine needed depends on (1) the diameter of the blank, (2) thickness of metal, (3) shape of the drawn work, and (4) the alloy used and its temper. Where there are large flat surfaces, a suitable air cushion inserted in the press is preferable to springs or rubber pads mounted in the draw tools to supply the pressure needed to prevent buckling, and to retain the desired flatness of the sheet in the finished work.

The table at top of next page gives the approximate sizes of blanks that can be drawn on various sizes of presses. They are practical working figures which have been proved to give satisfactory results in the press-shop in actual practice.

Tool Design.—Correct design of drawing tools is most important to achieve good results. The general principles are the same as for other metals, but the amount of reduction per draw, the radii on the tools, and the change in metal thickness will vary.

Reduction per Draw.—The following table gives reductions per draw in working the metal and its alloys :

Reduction per Draw		*Desired Reduction per cent.*	*Permissible Reduction per cent.*
Blank D	D	40	42
First Draw	D_1	40 D	42 D
Second Draw	D_2	20 D_1	25 D_1
Third Draw	D_3	20 D_2	18 D_2
Fourth Draw	D_4	15 D_3	15 D_3

These are safety figures, and it is found that trouble begins when they are exceeded. For hard tempers it is necessary to reduce the reduction per draw. The increased hardness increases the resistance of flow of the metal to such an extent that fractures may occur when using high reductions which are quite satisfactory for the softer sheet. In many cases the decrease in the reduction from that desired may amount to

Type of Press	*Capacity in Tons.*	*Maximum Diameter of Shell in In.*	*Maximum Thickness of Blank in In.*	*Maximum Depth of Draw in In.*
Double-action Toggle . .	63	8¾	0·051	4¾
,, ,, ,, . .	125	14	0·102	8½
,, ,, ,, . .	148	15½	0·102	9½
,, ,, ,, . .	282	23	0·125	10
,, ,, ,, . .	300	27	0·125	10
,, ,, ,, . .	360	25	0·125	14½
,, ,, ,, . .	400	30	0·156	12
,, ,, ,, . .	550	30	0·187	17
,, ,, ,, . .	500	37	0·250	14
Hydraulic	1300	49	0·315	24

Mechanical Properties and Composition of Aluminium Alloys

Alloy and Temper	*Ultimate Strength in Lb./Sq. In.*	*Yield Strain Lb./Sq. In.*	*Elongation per cent. in 2 In.*	*Brinell Hardness*	*Composition*			
					Si.	*Mn.*	*Mg.*	*Cr.*
2S–0	13,000	5,000	35·0	23	. .	. .	. .	. .
2S–¼	15,000	13,000	12·0	28	. .	. .	. .	. .
2S–½	17,000	14,000	9·0	32	. .	. .	. .	. .
2S–H	24,000	21,000	5·0	34	. .	. .	. .	. .
3S–0	16,000	6,000	30·0	28	. .	1·25	. .	. .
3S–¼	18,000	15,000	10·0	35	. .	1·25	. .	. .
3S–%	21,000	18,000	8·0	40	. .	1·25	. .	. .
3S–H	29,000	25,000	4·0	55	. .	1·25	. .	. .
4S–0	26,000	10,000	20·0	45	. .	1·25	1·0	. .
4S–¼	31,000	22,000	10·0	52	. .	1·25	1·0	. .
4S–½	34,000	27,000	9·0	63	. .	1·25	1·0	. .
4S–H	40,000	34,000	5·0	77	. .	1·25	1·0	. .
5S–0	29,000	14,000	25·0	45	. .	. .	2·5	0·25
5S–¼	34,000	26,000	12·0	62	. .	. .	2·5	0·25
5S–½	37,000	29,000	10·0	67	. .	. .	2·5	0·25
5S–H	41,000	36,000	7·0	85	. .	. .	2·5	0·25
53S–0	16,000	7,000	25·0	26	0·7	. .	1·25	0·25
53S–W	23,000	20,000	22·0	65	0·7	. .	1·25	0·25
53S–T	30,000	33,000	14·0	80	0·7	. .	1·25	0·25

10 per cent. in the first draw, and to 5 per cent. in succeeding draws, depending on the hardness of the metal which is being worked in the press.

Radii on the Drawing Tools.—The radius on the die should be approximately a minimum of 4 T and a maximum of 15 T where T is the thickness of the original metal, while that of the punch should be held to a minimum of 4 T. The sharper the die radius, the greater the resistance to the flow of the metal, and resistance to metal flow is the cause of fracture during drawing. On the other hand, if the radii are too large a great

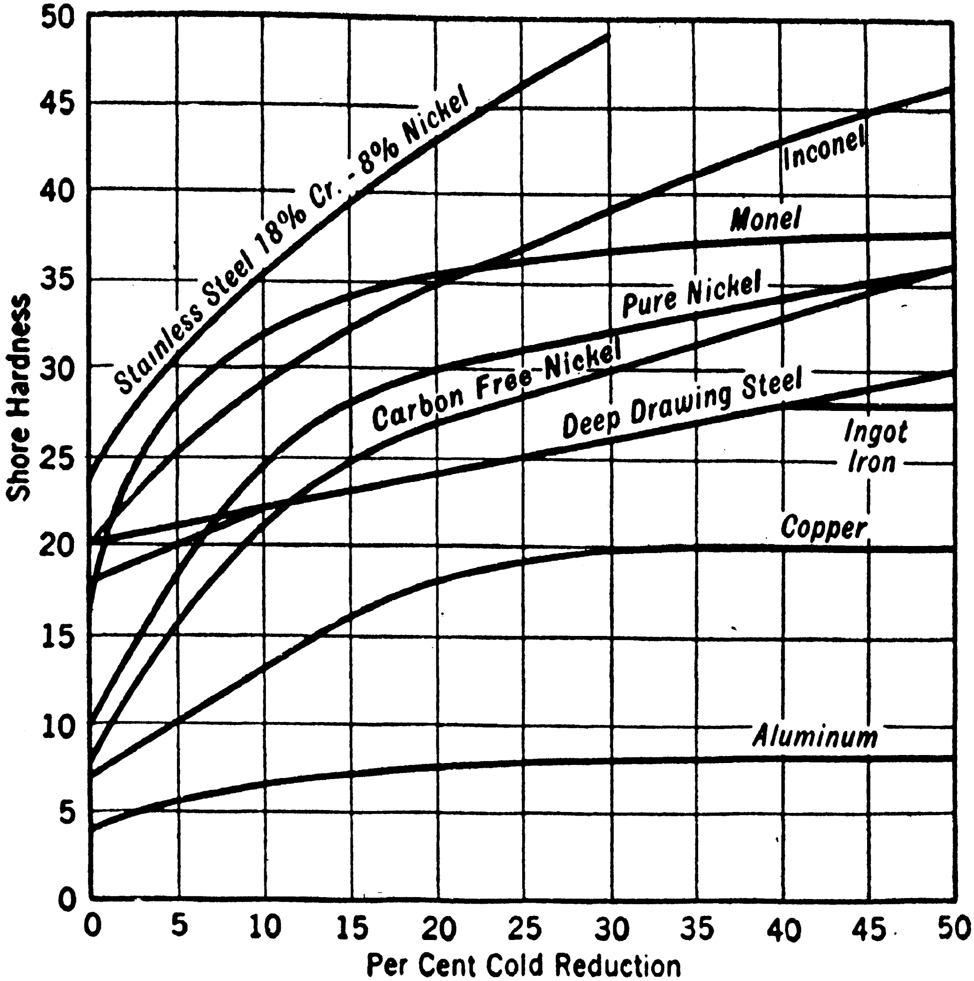


Fig. 1.—INCREASE OF HARDNESS OF VARIOUS METALS WITH COLD WORKING

proportion of the metal in the blank is not under control whilst being drawn, and this may cause the formation of wrinkles. A liberal radius on the vertical corners of rectangular shells is desirable, as otherwise there will be too great a resistance to the flow of the metal in that area.

SHAPE TO BE DRAWN.—Experiments prove that in drawing rectangular shapes the greatest movement of metal occurs at the corners. The die and the blankholder, therefore, must be so constructed as to control this flow of metal and then avoid both wrinkling and fracture. This can only be done by making the draw radius at the corners slightly larger than at the sides and ends, care being taken to see that the radii of the different lengths blend smoothly into each other. Increasing the draw radius at the corners helps to reduce the resistance to flow caused by thickening of

the metal. A procedure which is commonly used is to hollow out the face of the blankholder to provide the necessary clearance between the die face and the blankholder to allow for this increase in thickness. The clearance should correspond nearly to the increase in thickness, because if it is too great, buckles extending radially from the corners will form in the drawing operation.

Factors which Affect the Drawing Quality of Aluminium Sheet.—The factors which profoundly influence the behaviour of aluminium and aluminium alloys under the action of the press are grain size, mechanical properties, and the tendency to ear.

As regards grain size, there are no data to allow us to come to any precise conclusions, and refuge has to be taken in somewhat vague postulates. In general a fine grain is desirable. But for certain draws a medium coarse grain size gives better results. The Erichsen values have been used to correlate grain size with drawing properties, but there is nothing reliable to go on and, to say the least, it is taking a step into the unknown to take the Erichsen figures as a guide to drawing properties. All of which is in accordance with what the test tells of other metals. There is only one test that is satisfactory—the purely practical and empirical one of drawing the metal and seeing whether the results are satisfactory.

As to mechanical properties—tensile strength, yield strength, elongation, and hardness—it is generally assumed that the higher the elongation and the lower the yield strength, the better will the metal behave when it comes under the press. But the truth must be admitted that there is no definite relationship between mechanical properties and drawing characteristics. This is not surprising. To force figures to show such a relationship is to close an eye to other influences. The truth of the matter is, of course, that there are a number of other factors involved, and it is premature to try to set up illusory standards which bear no relation to the truth.

As to tendency to "ear," the ideal drawn shell, uniform in height and width of flange, can often, with aluminium and its alloys, turn into one with four or eight peaks and corresponding troughs. Different lots of metal give totally different results and, what is more surprising, the same metal will work perfectly and give no "earing" and then produce a perfectly "eared" specimen, without any obvious change in procedure. The result is serious loss from the production point of view. It is simple to reduce the blank size so that "earing" is suppressed, but sometimes suppression in this way will give an end result which is not sufficiently deep—which is no solution at all of the trouble. It is, of course, a matter of orientation of grain in the sheet, and that orientation is susceptible to various influences such as composition of the alloy, rolling procedure, etc. The shape of the shell to be drawn also influences the tendency to "ear,"

and round shells " ear " much more readily than rectangular shapes, undoubtedly due to the differences in concentration of the stress in the drawing.

Brass

In the copper-zinc system, six different phases occur and the relation between them is clearly revealed by the accompanying diagram (Fig. 2).

The Beta constituent undergoes a transformation at a temperature that rises from 453° C. to 470° C. with increasing zinc content. The change is one within the Beta space lattice and W. L. Bragg considered the effect to be due to the formation of a symmetrical space lattice. This

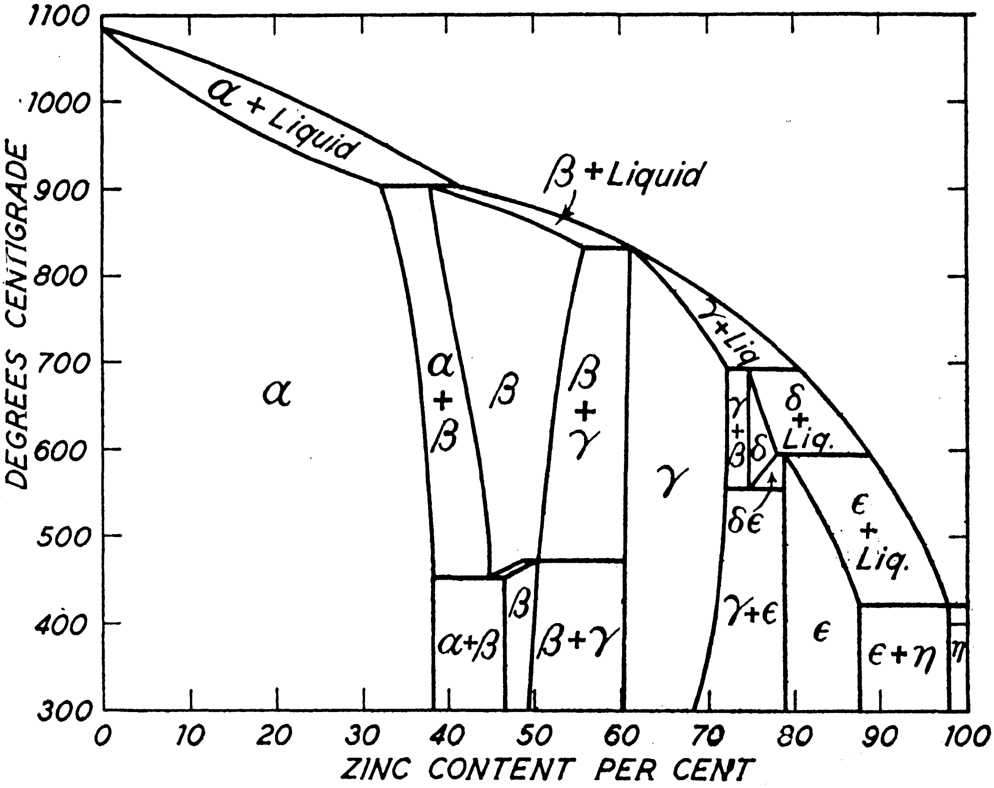


Fig. 2.—THE COPPER-ZINC SYSTEM

Alpha	stable between	0	and	38·1	per cent.	of zinc.
Alpha plus Beta	,, ,,	38·1	,,	46·2	,,	,,
Beta	,, ,,	46·2	,,	49·5	,,	,,
Beta plus Gamma	,, ,,	49·5	,,	60·2	,,	,,
Gamma	,, ,,	60·2	,,	68·3	,,	,,
Gamma plus Epsilon	,, ,,	68·3	,,	79·0	,,	,,
Epsilon	,, ,,	79·0	,,	87·3	,,	,,
Epsilon plus Eta	,, ,,	87·3	,,	98·1	,,	,,
Eta	,, ,,	98·1	,,	100·0	,,	,,

is now generally accepted as the explanation, as the result of the investigations of Owen and Pickup.

In considering this copper-zinc system, it is well to bear in mind that a great variety of states may be obtained. The number of constituents is large, as is the number of changes in the solid state. What is more, the rate of cooling is important and governs which of the many possible structures is finally realised.

Those alloys which solidify as alpha show normal skeletal crystals in the cast condition, a normal structure of polyhedral grains in the cast and annealed condition, and a normal twinned structure after hot or cold working followed by annealing. Alloys which solidify as alpha plus beta change to alpha above 400° C. Those which consist of alpha plus beta at atmospheric temperature solidify as beta and the alpha constituent is formed from the solid solution. Alpha is a solid solution of zinc in copper, and has a cubic lattice.

The improvements which have been effected in the production of sheet brass during the past twenty years give to the press worker a freedom from trouble and a uniformity of product which have resulted in the setting up of definite standards which classify the metal for press purposes into three grades. There are several reasons for this. Bright annealing in the modern continuous type of furnace with a controlled atmosphere gives a high degree of finish. The prime ingredients, copper and spelter, are available in a purity of not less than 99·90 per cent., and providing that rigid inspection is carried out in the addition of scrap, impurities are excluded from the first.

Basic-quality Brass

This, the lowest-quality brass, is defined by British Standard Specification No. 265 of 1936. The permitted copper content is not less than 61·5 per cent. and not more than 64 per cent. Lead less than 0·02 per cent. and iron from 0·02 to 0·05 per cent., with the less important impurities, bismuth, tin, nickel, and arsenic, also defined. The limits set for iron and lead are high. Deep drawing can only be effected with this grade if both these metals are considerably lower than the percentages specified.

65/35 Brass

British Standard Specification No. 266 of 1936 fixes the copper content of this grade between 64 per cent. and 67 per cent. A maximum is set for lead and iron. 65/35 brass is suitable for very deep drawings and is excellent for pressing operations.

70/30 or Cartridge Metal

This is covered by British Standard Specification No. 267 of 1936, and is defined as an alloy containing not less than 68 per cent. of copper

and not more than 72 per cent. It set the standard for deep drawing and is still the best. When there are several operations in sequence in the press-shop, when the shell has to be ironed, and when it is desirable to cut down inter-stage annealing to the smallest number of journeys through the furnace, it is unquestionably the best alloy to use. But the 65/35 brass sheet sets such a high standard that the exclusive field of the cartridge brass has been encroached upon.

Hardness of Brass

In the three specifications cited, the hardness of the sheet is defined, and full-annealing, annealing, or cold-rolling give to any grade a hardness falling within the requirements, but usually the metal delivered to the press-shop is in the fully-annealed condition, suitable for pressing and deep drawing. In all three specifications a maximum Vickers Pyramidal Numeral of 80 is set for fully-annealed sheet.

Deep-drawing Properties of Brass

A sheet brass may conform in every detail to the specifications mentioned, and yet fail under the press. The hardness and tensile tests, which are part of the specifications, do undoubtedly give some indication of what the behaviour is going to be when the metal is distorted, but it is limited. Nor do cupping and deep-drawing tests give the answer. The Erichsen test is the best known and others are the Avery test, similar to the Erichsen in that both draw ring and punch are of the same shape, but with the draw ring and clamping ring each serrated on one face ; the Guillery test, used in French practice, in which oil pressure loads the punch ; and the Jovignot test, also a French procedure, which differs fundamentally in that the distorting pressure is hydraulic, acting on one side of a specimen which is tightly held between the two flat faces of two rings. All these are cupping tests. The A.E.G. and Erichsen deep-drawing tests are different from those enumerated. The shape in the metal takes the form of a parallel-sided flat-bottom cup.

To describe the tests at length is beyond the scope of this book, but it is fair to say that these miniature testing machines give an indication of what is going to happen on the works scale. To claim more for them is unjust to them. Like any other tests, they require expert interpretation. With the data they provide, an experienced production engineer or pressman, who has a background of hard-won knowledge, is often able to predict, with some confidence, what will happen when a given operation is put into practice in the shop ; he will also be well aware when he is on uncertain ground. A man in charge of a machine with the power of veto, but without the necessary experience, results in the rejection of good material whose suitability for use is proved by the only ultimate test—the production of satisfactory deep drawings in the shop.

These remarks apply to metals generally and not to brass in particular. Season cracking, its cause and prevention, waving defects on pressing, and orange-peel surface effects have all been dealt with elsewhere.

What is called the beta constituent of brass can cause a lot of trouble, since it seriously impairs the ductility of the metal sheet. Not all brass containing the beta constituent fails under the press, but its presence, particularly if its dispersion throughout the mass of the metal is homogeneous, cuts down the margin of safety, and if that margin is exceeded, failure will result.

Stainless Steels

These fall sharply into two divisions according as to whether the basis is austenite (a solid solution of iron carbide in gamma iron) or ferrite, the chief constituent of low-carbon-content steels.

The deep-drawing properties of austenitic steels are well known. The " 18/8 " grade containing 18 per cent. of chromium and 8 per cent. of nickel, with a carbon percentage of 0·1 per cent. or under, is very flexible in its drawing and pressing properties, and is possibly the most resistant to corrosion, but the " 12/12 " variety, with 12 per cent. of nickel and 12 per cent. of chromium (the carbon being as before), is softer and exhibits maximum deep-drawing and pressing properties. Nickel is sometimes left out, and a range of stainless steels with a chromium content of from 16 to 24 per cent. have come into general use, with a ferritic and not an austenitic base.

The objection to austenitic stainless steel is that it is very hard on the tools and work-hardens rapidly. The 18 per cent. ferritic stainless steel has come into use because it does not work-harden so rapidly, and thus the necessity for inter-stage annealing is reduced. What is more, the temperatures of annealing are lower.

Many press-shop operatives of great experience and knowledge have very definite views about stainless steel, which are often far from favourable, in spite of the fact that metallurgists who know the requirements of a metal for deep drawing give it their approval both because of the high Erichsen values it shows and because of the stress-strain curves it gives.

That austenitic stainless steel scores and fouls all too readily unless the right lubricant is used cannot be denied. The pressures are heavy and the newer type of chlorinated mineral oils are the solution of the difficulty. In comparatively mild drawing, castor oil is effective. Proper control of inter-stage annealing is all-important. The crystal structure of the metal must be on the fine side if the deep draws are to be successful and should not be allowed to become unduly coarse in inter-stage annealing. It is of great importance to divide the successive drawing operations with a clear recognition of the work-hardening properties of the alloy.

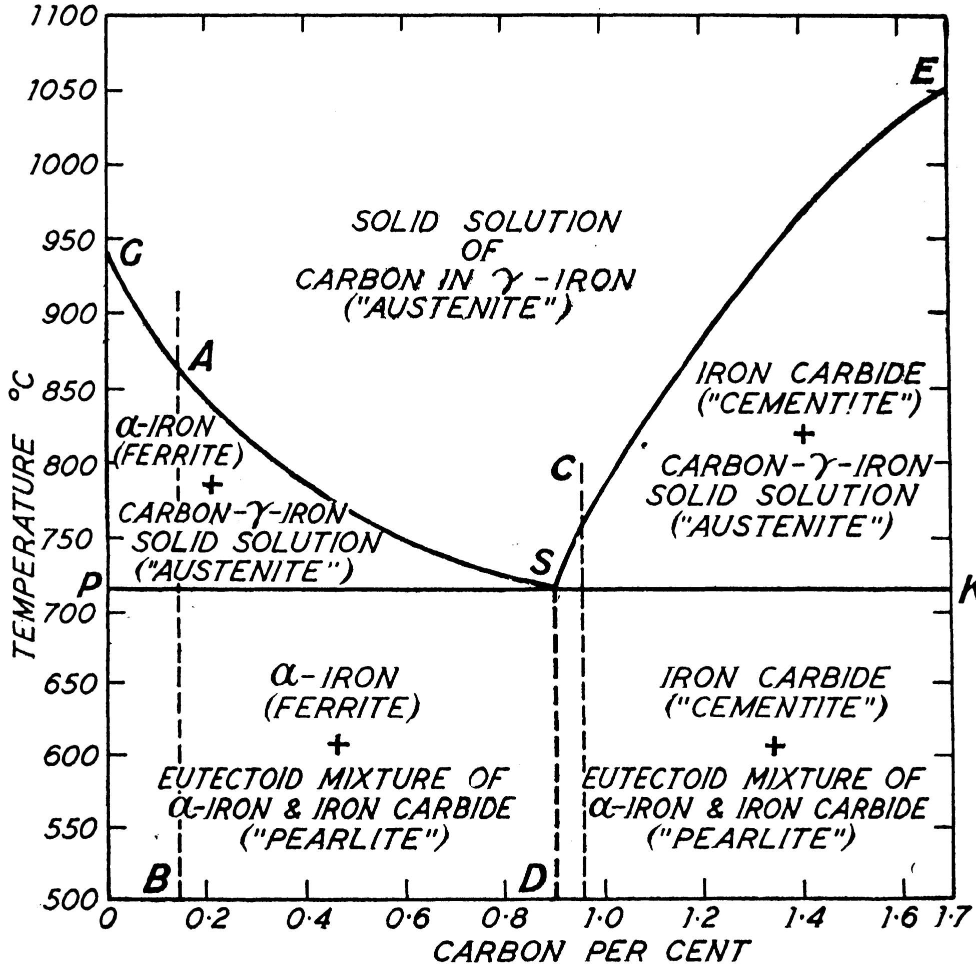


Fig. 3.—THE IRON-CARBON EQUILIBRIUM DIAGRAM

The austenitic stainless steels are not so prone as the ferritic to develop fractures in those parts which have been subjected to the "critical" amount of strain. To avoid this trouble the metal must be annealed at 1,000 to 1,100° C.

Nickel, and Nickel Aloys

Nickel and Monel metal, the impure copper-nickel alloy containing 65–75 per cent. of nickel, and 25 to 30 per cent. of copper, with about 5 per cent. of minor constituents, are capable of being very deeply drawn, provided that the "malleable" type which has been treated with magnesium or manganese (to deoxidise it) has been added immediately before casting. It is extremely ductile but very sensitive to

impurities, particularly to nickel oxide. Carbon and sulphur have the same effect.

Monel metal is not quite so ductile as pure nickel and resembles steel on the press. Indeed, tools made for working with steel can be used with no change for Monel metal, although it is usual to allow a slight increase in the radii in order to avoid fouling.

The alloy does not "iron" well, and it is usual in practice to reduce the diameter of the shell with successive draws. Inter-stage annealing has to be carefully watched, for when the hardness figures are of the order of 190 to 200 Vickers Pyramidal Number or B92 Rockwell, the limit is reached, and unless annealing is then carried out, surface fissures, which may not show at the time but which will certainly do so in the subsequent stages, are formed.

Two types of sheet of Monel-metal nickel and Inconel are made for deep drawing and stamping. There is, in addition, a Monel sheet of especially high finish which is particularly suitable for fabrication into counters, cabinet tops, etc. It can be worked in a press brake but not used for stamping or pressing operations.

STANDARD COLD-ROLLED SHEET.—This is rolled hot, lightly cold-rolled to gauge, bright annealed and levelled. It is available with an

Fig. 4.—DEEP-DRAWN PURE NICKEL MIXING BOWL, 8 IN. DIAMETER × 7 IN. DEEP

" as rolled " finish which is a ground, satin finish. This sheet is not so ductile as special cold-rolled sheet or strip of soft temper, but it can be used for draws of moderate severity.

Special Cold-rolled Sheets and Strip.—These are heavily cold-rolled and have a highly finished, cold-rolled surface. They have a higher ductility than standard cold-rolled sheets and are available in a range of tempers from dead soft to full hard. Soft-temper sheets and strip with fine to medium grain are the most suitable for deep drawing. The large-grain size which goes with dead soft temper is liable to give a pebble surface on the finished work.

A well-balanced series of reductions for light-gauge cylindrical shells, with no ironing, is 35 to 40 per cent. on the first or cupping operation, and 15 to 25 per cent. on subsequent draws. If the walls are held to gauge, the first and second operations may be as first mentioned, but after, each successive draw should be diminished by about 5 per cent. It must always be kept in mind that although these alloys are very plastic in their working, excessive reductions increase finishing costs because they tend to open up the surface of the metal.

In deep drawing both nickel and Monel metal, it is important to have the tools hard and bright and to lubricate properly, otherwise fouling assumes serious proportions. Provided that the pressures involved are not too great, and the tools are hardened to C62 Rockwell, there is no real difficulty, and for more severe work the Nitralloy steels and the high-chromium-content steels are available.

It is important to watch annealing temperatures closely. 850° C. was generally agreed as a reasonable figure for commercially pure cold-worked nickel, but, like every other metal, nickel is becoming purer in industry, and the purer the nickel the lower the annealing temperature.

Cupro-nickel, so largely used for bullet envelopes, is one of the very best of metals for deep drawing, and it has, in addition, an extremely low rate of work-hardening. It can be distorted to the maximum before annealing becomes necessary. This may have a bearing on the future use of the alloy as it offsets the relatively high cost of the sheet.

It sometimes happens that there is an epidemic of excessive " earing " and of actual failure in pressing these cupro-nickel alloys, where previously there has been no trouble. It is generally found that the fault lies with the sheet metal which has developed " directionality," whether owing to a variation in mill procedure or to a change in the rolling-annealing sequence, and is something that can only be decided by reference to the records of the supplier.

Nickel Silver

These nickel-copper-zinc alloys are the same as those known to the pre-1914 generation as German Silver, and the name is still sometimes

used for those low in nickel and the alternative for those with a higher nickel percentage. They vary in colour from white to yellowish-white with decreasing nickel content, and they owe their use in industry to the fact that they have a good silvery appearance and polish with a brilliancy which is very appealing on fittings. Nickel silver is the usual basic material for silver-plated tableware ; the market for the supply of alloy for this purpose is a highly competitive one and troubles under the press are not infrequently due to nickel with too high a percentage of impurities being used.

The nickel silvers may be regarded as being derived from alpha brass by the replacement of a portion of the zinc and copper by nickel whilst keeping their constitution within the alpha range. The relative proportions of zinc and copper have no great influence in this solution on the physical properties. Nickel, which replaces both to a certain extent, gives to the alloys added resistance to corrosion as well as added strength. Ductility is not impaired to any considerable amount. Even when there is some variation in the relative proportions of copper and zinc, there is a fairly definite relationship between the properties and the nickel content.

In the annealed condition the tensile strengths of the copper-nickel-zinc alloys varies from 25 to 30 tons per sq. in. Cold-rolling increases the values to 45 tons per sq. in. and over.

Nickel silver is somewhat in a class apart, as the working of this range of alloys is restricted to a comparatively few shops which specialise in the work. The properties of the various nickel-copper-zinc alloys are excellent from the press-shop point of view, and although they are harder than the brasses they resemble them in their working properties.

The copper content of nickel silvers is between 45 per cent. and 60 per cent. and the nickel percentage varies from a minimum of 5 per cent. to a maximum of 30 per cent. The following are the grades met with in English practice, although it is now becoming common practice to refer to a nickel silver in terms of its nickel content, e.g. " 20 per cent. " grade.

CLASSIFICATION OF NICKEL SILVERS

Percentage Nickel	*Approximate Percentage of*		*English Trade Name*
	Copper	*Zinc*	
35 . . .	45	20	Foundry Alloy
30 . . .	55	15	BB
25 . . .	58	17	Bar Best
20 . . .	63	17	A1 of Firsts
18 . . .	60	22	A
16 . . .	59	25	Seconds
14 . . .	58	28	Seconds
12 . . .	56	32	Thirds
8–10 . . .	59–57	33	Fourths
5 . . .	60	35	Fifths

The percentage of zinc varies with the nickel content: in the lowest grade or " Fifths " it is as high as 33 per cent.; 20 per cent. nickel carries 17 per cent. of zinc and 15 per cent. of nickel goes with a 30 per cent. of zinc. Practised workers in this field are at variance as to the effect of zinc on the drawing properties. Some assert that the casting procedure is all-important, which it undoubtedly is, but others insist on a decreased zinc content as the draw increases in severity. There is no doubt that the lower the zinc content the lower the rate of work-hardening and the less the tendency to foul the tools. It is equally certain that a low zinc content makes for safer annealing, as there is less tendency for the grain of the metal to coarsen. All of which is justification for the insistence of some users on a specified zinc percentage.

The tools used should be of tungsten steel for heavy draws, with a carbon content of about 1·75 per cent. Nitrided steel tools also give excellent results. Lubrication is important, and the new chlorinated oils of high film strength, which have proved so useful in drawing steel, are recommended.

Inconel

Inconel is a proprietary nickel-chromium alloy (80 per cent. nickel, 14 per cent. chromium, and 6 per cent. iron is typical) which has valuable anti-corrosion properties at high temperatures. In the press-shop it requires the same treatment as some of the more resistant steels. The tools must be hard in the extreme and well finished on the surface. As to lubrication, the same remarks apply as to stainless steels.

Inconel requires very special annealing treatment. It is held at a temperature of just under 1,000° C. for a quarter of an hour and then water quenched. But 1,000° C. must not be exceeded or the grain of the metal is altered with serious effects on its drawing properties. After final deep drawing the internal stresses are relieved by holding the article in the furnace at 750° C. for 1 hour, or somewhat longer. Inconel is now largely used for aero-engine exhaust manifolds, and also for the manufacture of hot-plates, for both of which purposes it is extremely satisfactory. It is likely to be further used, and more frequently seen in the press-shop in the future.

Zinc

The main use of zinc in the press-shop is in the making of the outer cases of dry electric batteries by the extrusion process. Provided certain well-defined conditions are observed, the metal flows easily and smoothly and perfect cylinders are produced at rates which depend upon the press and the size of the cylinder extruded, but which commonly exceed one per second, although lower rates are more usual. These conditions are (1) that the metal must be pure, and (2) that at the moment of impact with the die the zinc must be at a temperature between 180° and 210° C. Since

both conditions can be satisfied, the production becomes a routine process. Electrolytic zinc is available in a purity of 99·99 per cent., and to supply " dumps " or blanks at the right temperature presents no difficulty.

Zinc can be deep drawn and is capable of a high degree of distortion under conditions which are accurately known. These emerged from the classic researches of Mathewson, Trewin and Finkleday, published in the *Transactions of the American Institute of Mining and Metallurgical Engineering* (see references at end of book). The conditions are (*a*) zinc of 99·99 per cent. purity and of average grain size not exceeding 0·05 mm. must be used ; (*b*) the temperature of the metal sheet must be from 40°–50° C; (*c*) the tools must be well finished to prevent fouling; and (*d*) the work must be suitably lubricated.

Deep drawing of this metal is not of great commercial importance, because pressure die casting does all and much more than a crank press can do in producing a wide range of shapes.

Precautions must always be taken against the tools becoming too hot in the course of a long run. This is always liable to happen and the result will be the production of unduly large crystals with consequent loss in tenacity, and the production of a high percentage of scrap. For zinc recrystallises at a comparatively low temperature, and when once this has occurred, with increased grain size, nothing can be done to reverse the process.

With zinc sheet for drawing, two points must be watched—orientation and crystal size. As regards the latter, if the limit of 0·05 mm. already mentioned is exceeded, the tenacity of the sheet falls away rapidly. This same large crystal size will often simultaneously engender a rough surface, etc., and work will either fracture or suffer from surface blemishes which make it unsuitable for use. " Earing " can be so marked on cylindrical shells that the troughs of the waves come well below what is the desired height in the finished work.

Zinc seems very catholic in its tastes as regards lubricants. Mineral jelly gives excellent results, but so do soluble oils in the form of " suds," and it is common practice to take blanks direct to the die from a heated bath of " suds."

Copper

Copper is obtainable commercially in a high state of purity. As regards the press-shop, its qualities and defects can be very simply stated. It is highly ductile and work-hardens slowly. Its low tensile strength and softness permit of a high degree of distortion being performed in one operation. And copper " irons " well. On the other hand, the low tenacity results in fracture of the walls of the shells if the flow of the metal, after passing through the radius of the die, is too much restricted.

There has been great improvement in the quality of the metal of recent years from the press-shop point of view, although for more than

two decades it has been freely available commercially in a very pure state. High conductivity and arsenical copper of the tough-pitch varieties are two grades commonly used in press work. There are also the higher-priced oxygen-free and deoxidised varieties of the metal, the phosphorus deoxidised being most commonly met with. The two latter are more suited to severe cold working but, on the whole, there is great similarity in mechanical properties of the four types—the tensile strength being from about 15 tons per sq. in. up to 25 tons per sq. in. in the annealed and hard-rolled conditions respectively. But oxygen-free high-conductivity copper must always take the place of the ordinary "tough-pitch" variety when the work is to be welded autogenously after passing through the press. The enhanced price that has to be paid is more than justified.

Copper calls for little comment as regards the technique needed to deep draw it successfully. Normal speeds of drawing suffice, the radii of draw rings and punches are of no importance, and annealing for stress relieving is unnecessary. Ordinary "suds" suffice for lubricating light draws, and vegetable oil or animal fat for heavier working. The only point worth mentioning concerns tools. Copper is soft and tools load readily. Expensive tool steels are not necessary. Mild steel, case-hardened, does all that is required, although some go to the expense of a chromium finish, and consider the additional cost more than justified by the "trouble-free" working that it gives. But lubrication is a simple solution and soluble oil in soap dissolves most of the difficulties.

Chapter VIII

LUBRICATION IN PRESS WORK—EFFECT OF LUBRICANTS ON THE SKIN

ALTHOUGH the lubrication of dies and metals which are being worked in pressing and drawing may seem outside a book devoted to power presses, yet the subject is so intimately bound up with the performance of the machines that a summary of our present knowledge seems desirable. In spite of the attention that has been devoted to this particular aspect of lubrication in recent years, the literature is meagre and there is definitely a lack of precise statement. That is inevitable, for much research work and correlation of data still remain to be done. Press operators and production engineers have, in the aggregate, a large amount of information and a wide general experience of what is suitable for certain operations—but the knowledge has yet to be pooled for the benefit of the industry as a whole. The research worker has not yet arrived at the stage where he can lay down a definite set of standards for the various metals under the great variety of conditions met with in practice, and this obviously is unhelpful to the practical man who cannot, for the want of such definite standards, be anything but empirical. Even when information is exchanged between press operators, the lack of scientific basis is frequently seen. For one production man, who may be doing heavy draws on a metal with indifferent success, will try the lubricant recommended by another who is also drawing the same sheet and getting very excellent performances : but the results will be the reverse of satisfactory. Obviously there are too many variable factors, some of which are unknown.

In the past the quality of a lubricant was judged by its " feel " in the first place and then by the results it gave. It might be objected that the words " in the past " are superfluous since, in spite of all that has been said on the subject, the ultimate test of a lubricant—whether oil, grease, or filler in an oily base—is what it does when actually used on the metal when the deformation is taking place under the press.

Secret formulas not only were, but still are, cherished secrets. The days when performance was limited by the lubricant have passed. The old practice was to cast round for a suitable substance, using the method of trial and error if the secret compound failed, and then, if nothing was found, to reduce the amount of work involved in the operation.

But the freer interchange of knowledge is the only solution. For simple blanking no real difficulties of lubrication arise. A quite perfunctory application of oil by passing through rollers usually suffices.

Ease of Application

How efficiently the manufacturers of lubricants had done their work in applying this knowledge is evidenced by the almost casual application of a few dabs of one of the lubricants commonly used in the work, and this seems, for the most part, to work quite well. But with the more viscous lubricants such as are used on thick steel, greater care should be exercised. Local scoring and fouling can soon assume formidable proportions and cut down production, unless there is fairly even distribution.

Removal of Lubricants after Drawing

Once a drawing operation is completed with the aid of a lubricant, what remains of it on the surface should be removed as completely and rapidly as possible. Staining can be a grave defect and solid fillers in lubricants leave behind particles which aggregate together and are harmful in succeeding operations. If a solid filler dries on the work which may be annealed with traces of it still on, a succeeding and milder draw will suffer owing to increased friction, for the residue of the filler does not spread uniformly to the same fine state in which it was originally used in the first draw. It is no longer a lubricant but an abrasive.

Steam or jets of hot water will do a good deal more than a mere agitation in hot water. Vegetable, animal, and mineral oils can be taken off by trichlorethylene. A cheaper method is an alkaline wash, but soap should be added to the alkaline lye in the case of purely mineral oils. To deal effectively with all three classes of oil the alkaline bath should be able both to saponify and emulsify. Thick greases can be removed in the same way but they take more time : sprayed liquid is more speedy. An organic solvent such as trichlorethylene will dissolve the oily part of the grease but leave the soapy part behind, so that subsequent washing in hot water is necessary.

The removal of adherent solid fillers after drawing calls for hand work, high-pressure sprays, or mechanical scrubbing.

There are a large number of proprietary cleaners on the market, of varied and complex composition, but the essential thing is that the cleaner should have high emulsifying power. A very simple method of testing the value of a detergent is to mix 1 part of the lubricant with 10 parts of the cleaner and shake vigorously in a corked or stoppered bottle. If an emulsion forms rapidly and remains stable on standing, the cleaner is suitable for its purpose. Sodium phosphate—the trisodium salt—is an extremely useful addition to cleaners and is much in use. But a cleaner which is sprayed under high pressure from jets will always be more effective than when used as a bath, although mechanical or hand

scrubbing will often prove quite adequate. If heavy greases and oils with fillers prove difficult to remove, a preliminary brushing with paraffin will often overcome the difficulty. Calcium soaps are troublesome but baking before washing is invariably effective.

Trichlorethylene is the most popular method of degreasing, and if one treatment is inadequate two machines in series will prove effective in most cases. The form of machine in which the metal actually immerses for a time in the liquid and then is again exposed to the washing for the condensing vapour has increased the efficiency of the method. Where the lubricant is an oily base containing a filler, a subsequent alkaline bath is needed to complete the process and remove the solid matter.

Dermatitis due to Lubricants used in Press Work

Skin affections, although less common in press-shops than in machine-shops, do occur, and no production engineer can afford to ignore them. "Dermatitis" is a generic term for any skin eruption and the various clinical types which occur are largely a matter of environment. The use of lubricants which are harmful is not permitted and careful supervision is carried out. Although it is the counsel of perfection to say that adequate protective measures should be laid down and enforced so that ill-health from dermatitis should be eradicated, there are the ordinary health hazards inherent in press work, and all that can be done is to gradually tighten up control so that casualties are reduced to a minimum. There can be no doubt that the occupational dermatitis, like many other skin affections, would show marked decrease with the freer use of soap and water in general, yet that is only true in part, and social conditions, as well as the habits of the workers, are important factors.

It is a natural psychological process for a worker to handle a really dirty lubricant as little as possible, and if production is to suffer by the inadequate application of a highly efficient but dirty lubricant, a compromise has to be made and the saving in health and minimising of defective drawings balanced against the loss caused by something not quite so effective but more easily handled. The elementary psychology is one of which every production engineer and executive is well aware and it is purely a question of outlook.

The first signs are usually "blackheads," without any actual inflammation. Such a condition is likely to be followed by inflammation and the development of a flat rash, which in turn may become papular or pimple-like: or the pimple-like rash may be the first sign of the oil effect. The pimples frequently become infected or pustular, in which case they may become troublesome and even incapacitating when sufficiently extensive. This rash may also appear on the neck and on the face if the oil finds its way there, although the backs of the hands, the forearms, and the extensor surface of the thighs are the more usual sites.

The Skin Condition and its Cause

Several reasons have been advanced to account for the occurrence of this particular occupational dermatitits—e.g., fine metal particles perforating the skin.

It seems generally agreed that the prime cause of oil dermatitis in press-shops are oil and dirt blocking the minute passages in the surface of the skin, the sebaceous glands, and the hair follicles. The natural oily secretion is thus held back and, not being able to escape, it accumulates and hardens and finally, since it is a foreign body, it irritates and dermatitis ensues. This is usually considered to be the main effect which occurs, whatever the character of the oil used, whether mineral, animal, vegetable, sulphur, or chlorine derivative.

Some dermatologists say that petroleum oils have the property of defatting the skin and taking from it the natural greasiness which is an essential to its healthy functioning ; vegetable oils and fats have not this property, and their admixture with petroleum oils offsets the defatting action of the latter, although, in mixtures of the two, they are usually present to such a minor extent that the defatting petroleum action is entirely dominant.

But all oils, whatever their character, may plug up the pores of the skin and form comedones. Skins which are naturally greasy and with active sebaceous or fat-forming glands are less prone to show reaction to the defatting action of lubricating oils. The worker with a dry skin will always be more prone to this type of trouble.

Infected follicles may develop into boils and even into carbuncles. Metallic particles, slivers, etc., can cause wounds of the skin which become infected and result in boils or cellulitis. The action of lubricating oils may result in drying, cracking, and fissuring of the skin. These fissures and cracks are an easy port of entry for bacteria, and the secondary infections which occur bring their own train of sequelæ—boils, lymphangitis, and, in extreme cases, if the general health is bad, septicæmia. Those who are subject to dry, harsh skins are the most likely to be affected, because the sebaceous glands are not sufficiently active to replace the fat extracted by the oils.

A small percentage of the workers show small, flat brown blebs on the parts touched by the oil or oil-soaked garments.

Allergic eczemas are the least frequently seen. They arise from hypersensitiveness to the particular oils used, or to one or other ingredient of the lubricant. The allergic type of oil dermatitis is best handled by taking the worker away from all contact with the causative agent and then treating the dermatitis. Consult a doctor when it appears.

Allergic occupational dermatitis usually begins on the hands and the arms, and on parts of the body which are in contact with the oil or with oil-soaked garments.

With the advent of women into industry, the whole subject has assumed more formidable proportions. Without going deeply into the subject, it is obvious that the softer and more susceptible skin of a woman is more susceptible to this particular type of occupational dermatitis than that of male workers. Usually, where there is a large percentage of female labour, there is also a competent nurse or welfare worker who can help a good deal by preaching sound doctrines of personal hygiene and unobtrusively but authoritatively seeing that a reasonably high standard of cleanliness is maintained.

Prevention

Prevention of dermatitis from lubricating oils consists, therefore, chiefly in cleanliness of the person, of the clothes of the workers, and of the oils themselves. Adequate washing facilities should be available. Toilet or liquid soap should be provided, and the use of paraffin or petrol should be expressly forbidden. Careless workers are apt to use paraffin or petrol to remove grease and oil from their hands and arms quickly. Others will use sand or sand and soap, or soaps with a high percentage of alkali: the use of chloride of lime or bleaching powder is not unknown. Even the healthy skin of a healthy subject will not stand such treatment indefinitely, and those whose skins are naturally dry and sensitive will chap and fissure almost at once when subject to such drastic measures.

Towels should be provided, and waste, which is not re-washed, is a great help in giving a preliminary cleaning and thus encouraging the workers to maintain a reasonable appearance of cleanliness in the towels provided.

Since the most frequent type of occupational dermatitis met with in the press-shop due to the lubricating oils used is a folliculitis and boils, cleanliness is much more important than protective ointments.

Differential Diagnosis

It does not follow that every worker who suffers from skin trouble is suffering as the result of the action of lubricants on his or her skin. Lubricating-oil folliculitis, boils, and dermatitis must be differentiated from these same conditions arising from non-occupational reasons. The hands, forearms, thighs, and legs are the most usual sites with workers in the field we are discussing. Non-occupational boils usually occur on other parts of the body, such as the back and the neck. Those boils, etc., which arise from contact with oil in the course of work are usually multiple and are seen in patches or clusters, whilst the others are solitary and there will be only one or two boils or furuncles.

The Adsorbed Surface Film

The fundamental point is that in heavy drawing the film of lubricant separating the two surfaces is of a different order of thickness from that

ordinarily met with when the lubrication of moving machinery parts is involved. The film is very thin, even approaching molecular dimensions, and the surfaces of the two metals are involved in an entirely different way from machinery surfaces which slide over each other and are separated by a film of oil. The problems of machinery lubrication are well known, and the various oil suppliers produce lubricants to meet the needs of industry. But in metal rolling and deep drawing the lack of scientific standards makes the whole picture very different. The conditions under which metal is caused to flow under cold operation introduce their own sets of problems. When metal is compelled to deform either in wire, sheet, or pattern, a force is applied to the surface which must be considerably greater than the metal resisting the deformation. Just what that force is must depend upon the metal and the amount of metal which flows at any one moment. In the region of high pressure a great strain is imposed which is not usually capable of being relieved by ordinary lubrication methods. A mineral oil, however high the grade, however suitable for reducing friction in machinery to a minimum, may have little effect. But if that oil is treated with certain chemical agents it begins to have an effect, not because its lubricating value as judged by ordinary tests is increased, but because it can now form a film which is so linked with the metal structure that it can be regarded as part of it. This is what is known as the adsorbed surface film.

The value of a deep-drawing lubricant is thus held to depend essentially upon its capacity to form, with the metal which is being drawn, the adsorbed film. This film is slippery, uniform, and stable under pressure, and the very high local temperature met when the die is at the height of the draw.

The " Stick-slip " Theory

Some of the most outstanding contributions to lubrication problems have come from the Physical Chemistry Laboratory, Cambridge, by Bowden and his collaborators. They are well worthy of the notice of the practical man because they are factual and no unwarranted deductions are made by them from the experiments. The conclusions drawn from them are logical. They express fact and not vague opinions or isolated experiences which look extremely promising but when examined are found incapable of exact interpretation because they are subject to too many variable factors.

When two metal surfaces are in contact, even when they are highly polished, planed, and prepared in a manner which frees them from the irregularities inseparable from the ordinary well-finished surface of the machine shop, the actual area of the two metallic surfaces making contact represents not more than an infinitely small percentage of the two areas. Actually, in the case of two such typical metallic surfaces of area 1 sq. ft. the contacts were limited to 0·0001 sq. in.

The Influence of Temperature

Bowden considers the temperature changes when one metal slides over the other as being extremely important and proves that with increasing load there is increasing heat development. The loads need not be high for the temperature increases to be important, and easily reach the melting-point of one of the two metals which are in contact. And it is the metal of lower melting-point which " polishes " in the course of being worked under the press, the other being comparatively unaffected. Obviously the total amount of heat developed influences the effects when the melting-point is once reached. The metal polishes and the surface discontinuity on that metal no longer exist. The tiny tips of the irregularities are raised to melting-point temperature, and the molten metal will travel as far as it is able within a small fraction of a second into the valley to freeze solid. When this process is multiplied many times, clearly a measurable change in the surface format occurs. Not merely does the geometry of the surface change, but the structure also. The crystalline configuration is destroyed and an amorphous layer is superimposed. This so-called Beilby layer is of the utmost importance in scientific study; not merely to the scientist in his laboratory, but to everybody who is responsible for the conveyance of intrinsically high loads over a metallic surface.

Motion of one metal over another is not continuous, but proceeds in a series of impulses. The tiny crests on the surfaces are made to engage each other when the pressure is sufficiently high to reduce the oil film to almost negligible thickness. The friction between them elevates their temperature to welding-point. As the metal moves forward the metal bridges thus formed restrain the movement, but only long enough for them to be elongated and finally fractured. This bridge building and bridge shattering goes on all the time and is manifested as metallic friction. Of course, the time taken to complete one cycle is very short; how short depends upon the relative speeds of the two opposing surfaces. This is the " stick-slip " theory. Even when an oil is present it goes on just the same, provided always that the oil film is not thick enough to exclude metal contact. Stick-slip can be considerably reduced by the aid of some fatty oils, and by anti-weld organic chemicals. The target for good lubrication is smooth motion, therefore stick-slip is to be eliminated by any means known to science. Lubrication is not solely restricted to stick-slip effect. If it were, it would be a far simpler problem.

Oiliness and Slipperiness

It is stating the obvious to say that any property which reduces the friction between the tools and the work will cut down the power needed to perform a given press operation. Already it has been explained briefly how friction can be interpreted and the mechanism by which it can be

reduced, but nothing has been stated about that much-abused word "oiliness." Abused because it is so ill-defined and so easy to misinterpret.

Oilness is now recognised as an abstract term, intended only to draw attention to some vague property which may be the antithesis of friction. A mental picture of it can be painted as an adsorbed surface film in which certain constituents of the lubricant are selectively attracted to the metal surface. Those compounds may be fatty oils, chemical compounds, or substances which have a greater attractiveness for metals than the sustaining oil. Frequently they are referred to as polar bodies. They form a blanket on the metal over which the main film of lubricant flows. The oil is thus insulated from the metal by an almost frictionless pad. How effective this pad is in reducing friction is a measure of oiliness. Some materialists are not content with this explanation. They state that all the properties of oiliness can be accounted for by the ratio of the thickness of an oil at atmospheric pressure and the thickness at high pressure. When a bulk of mineral oil is compressed it will thicken up by as much as thirty times, whereas a fatty oil will only increase in viscosity by about eight times. Both views are attractive, but we do not know which is true.

Slipperiness has no real place in lubrication nomenclature. But for convenience it can be associated with solid lubricants. Sometimes finely divided solids are introduced to oils and greases for the sole purpose of keeping surfaces apart. Hard solids such as sand would abrade, because they will not yield readily to a shearing force. A solid lubricant must be structurally soft and capable of easy resolution into smaller particles. Sulphur, for example, is made up of a bunch of crystals adhering to one another. By an applied force the aggregates can be broken down into individual crystals, and if the temperature is high enough be liquefied. Zinc oxide, on the other hand, is not crystalline, but amorphous. It is held together by a power of molecular attraction which, too, succumbs to applied pressure. Graphite appears to be different in that it is a crystal possessed of cleavage planes at which the crystal parts with layers of graphite when a force is applied to one of its faces. Mica behaves somewhat similarly. This ability to disintegrate could well be called slipperiness. Solid lubricants are used in metal working. Kaolin, or china clay, exists in such minute particles that it can be deflocculated in water or oil in water emulsions. In this way it is used in some deep-drawing operations.

Which of these different agents shall be used depends upon several conditions. Primarily surface finish may be essential, and having obtained it electroplating is the next operation. To achieve even distribution nothing must be present on the surface which will retard or prevent deposition of the plating metal. Perhaps galvanising is required. The subsequent treatments largely control the selection of the lubricant

used in the metal working. Power reduction can be effected in some jobs by the use of graphite, but as it is so difficult to remove its use is restricted.

Spreading Power

The quality of spreading easily is intimately bound up with the chemical constitution of the substance used as well as its physical structure. It is well known that water does not spread on an oily surface. Just why some substances will spread and some will not is outside the scope of this book. Solid fats obviously cannot spread evenly unless they are melted. Viscous lubricants would be sluggish in their desire to spread. Greases and thick emulsions must be spread mechanically. Natural spreading is something quite different from smearing or flowing down an inclined plane. It is an internal force within a substance which propels it in all directions, up hill and down dale, wetting everything as it moves forward until it strikes a barrier. The spreading of a fluid and the wetability of a solid are two tremendously important properties in the affairs of man. The simple operation of washing is possible due to the wetability of the skin or fabric with soap. So, too, lubrication would be impossible with fluids if they did not spread and wet the surface. (It should be stated here that in science wetting is not restricted to water, but includes all fluids.) A penetrating oil is a special type of lubricant possessed of extraordinary spreading power, not necessarily on a flat surface, but down cracks and around threads. Sometimes this penetrating power is made use of in rolling. The so-called bite is due to a rupture of the oil film succeeded by a rapid healing of the wound by virtue of the high speed of spreading. There are various ways of introducing bite into a lubricant either for cutting or rolling. Sometimes a solid lubricant is used for no other purpose than to spread with the lubricant and act as a sponge to maintain a required thickness.

Common Lubricants used

Lubricants for light rolling or drawing operations are oil in water emulsions, kerosene, and light mineral oils. Many skilled men have their own secret formulas for emulsions. Maybe they are very efficient, but often they are poor scientifically. By this is meant that a satisfactory result is obtained but not necessarily in the best way. Emulsions are often used, but how often are they made as good emulsions should be made ? The making of good emulsions is a highly skilled manipulation and is therefore best left to the expert. Of course one is not forgetful of little tricks, and secrets, acquired by skilled men in the metal industries ; on the other hand one cannot be unmindful of the disclosures of arts by scientific research and discovery. For many years wire-drawing lubricants have remained unchanged, so long that it hardly seemed likely that anything new was possible, yet lately research has stepped in and shown that improvements can be made.

During the last few years lubrication has been undergoing a transformation, and it is possible that within the next few years the lubricants of to-day will be only the carriers of chemical additives which will be the real lubricants. Just how far these additives will develop is difficult to forecast, but it is certain that they will develop and develop rapidly. Already they are used extensively in many classes of lubricant. Not only is attention being given to additives, but to treatments of metals for the purpose of giving them a surface coating. The most popular treatments are with phosphates. So far they have not found application to metal rolling or drawing.

Chapter IX

DEFECTS IN FINISHED PRESS WORK

As every press operative, tool designer, metallurgist, and production engineer is well aware, in spite of the large amount of major research work that has been done of recent years on problems touching the industry, press operations are still far from being free from troubles other than those common to engineering production in general.

Science has done much to define the possibilities and limitations of metals and machinery, but pressing and drawing, and the many operations associated with them, call for a high degree of pure craftsmanship, implying in the workman a special capacity for the work, an intuitive feeling for the nature of a metal, and not least, long years of experience. In press work there are factors which the scientific worker, whether he be engineer or metallurgist, frankly admits are difficult to explain. No doubt, with the ever-accelerating pace at which investigatión goes on in laboratory and in the works, much that is still obscure will be cleared up. But admitting all this, it is still unfortunately true that the light research has thrown on difficult problems has not, in many cases, been communicated to the press shop, where the information would undoubtedly be welcomed.

Compared with the materials available a few years ago, the standard of sheet metal supplied to-day to the press is immeasurably higher than it was. But the call for still higher production figures occasionally results in metal not being put to its best use and the results of metallurgical research not being properly exploited. The metallurgist then feels that his metal is not being properly worked or is being asked to do the impossible, although he has to face the undoubted fact that press work is, in many ways, an art as well as a science.

In summarising some of the troubles and defects which slow up production by producing imperfect articles, the object is to enumerate common causes and the obvious methods, when known, of preventing them. The list of references to original papers is by no means complete, but it serves the useful purpose of enabling a press worker to see what others, acutely interested in his own particular problem, have to say about it. Exchange of opinion and pooling of knowledge are invariably clarifying. Press work is no monopoly of the English-speaking people, and much has been published about the industry in other languages. In the following notes these papers have been taken into account and the various headings, if brief, are up to date.

Stretcher-strains

Luders lines have already been mentioned in connection with the plastic state in metals. A typical picture of them is shown in Chapter VI. They are visible to the naked eye and no microscope is necessary. It is a peculiar type of deformation, quite typical of annealed steel. As has been said, narrow blocks or layers of the material inclined at an angle of about 50 degrees to the direction of principal stress, flow abruptly as soon as the yield point is reached, whilst the material between the layers remains undeformed. As a consequence the surface becomes banded by the resulting elevations and depressions. Scale and paint, if present, break off in a corresponding manner. As already stated, the phenomenon is very troublesome in deep drawing and in pressing. These irregularities, variously called Luders lines, stretcher-strains, worms, Hartmann lines, persist until the degree of work increases to a certain value. This corresponds to the yield point *jog* in tension, which decreases with increasing carbon content. It is higher with smaller grain sizes and with rapid rates of loading. The true cause of the yield-point elongation, the contour of the stress-strain diagram in this range and the appearance of stretcher-strains in steel, is not yet clearly explained.

The phenomena are typical of the behaviour to be expected from a matrix of grains of soft material surrounded by a hard continuous network such as might be formed by cementite inclusions.

Other metals, such as aluminium and aluminium alloys and alpha-beta brass with small beta inclusions, also show strain markings similar to stretcher-strains.

When they once appear they remain even through several subsequent shaping operations in spite of the fact that the difference in level between the top of these wedge-shaped markings and the adjacent metal may be as small as 1/1,000th in. To smooth them out by polishing or grinding is uneconomic, whilst if they are allowed to remain they may render the finished article of little or no commercial value.

A great deal of attention has been devoted to the causes and prevention of this trouble, particularly in America by those engaged in the automobile industry. It was at first thought that stretcher-strain markings were due to dissimilar properties of the surface layers and the core in sheet rolled from segregated steel ingots. This view is not now held, and it is generally accepted that they are the surface manifestation of solid distortion wedges in the metal beneath.

Stretcher-strain does not appear in pure iron when subjected to pressing. But a very low-carbon steel sheet (0·04 per cent. of carbon) will show the condition in an extreme form. The carbon content of the sheet metal used for deep drawing and pressing varies between 0·05 and 0·11 per cent. and the tendency to develop markings decreases with increasing carbon content, although not to the extent of being of commercial importance. When the carbon content rises above 0·2 per cent.,

however, there is very marked reduction and medium-carbon steels are free from markings, even when deformed within the dangerous range of 0 to 4 per cent. true elongation.

"Temper-rolling" of the sheet metal by the supplier is the best safeguard against stretcher-strain markings appearing after passing through the press. "Temper-rolling" (it is also known as "skin-pass" or "pinch-pass") is a special form of cold rolling which gives a reduction of between 0·5 and 1·0 per cent. Finer limits within this range can be worked to. Temper-rolling is not permanent. It wears off with time, and therefore the production engineer has to ensure steady, even flow of sheet metal. But although co-operation between him and the supplier is of great help, it has its disadvantages in tieing him to one source of supply. The sooner the metal is used the better. Alternatively, the sheet or blanks can be roller-levelled in the works themselves immediately previous to pressing. In hot weather the percentage of failures due to stretcher-strain markings increases sharply. This is simply due to the fact that the effects of the previous mechanical treatment pass off more rapidly. The cost of roller-levelling is small. The blanks or sheets must be passed through the rolls both sideways and endways and, if possible, diagonally. But roller-levelling is very transient and may pass off in a day, whereas temper-rolling lasts for weeks.

With the demand for ever-increasing output, one method of avoiding stretcher-strain, namely, by dropping the speed of pressing, is not often available. But the production manager should, in analysing the causes of stretcher-strain manifestations, always take the speed factor into account.

Apart from seeing that the steel sheet supplied is the best for the purpose, the actual manufacturer of the pressing should also do his best to see that articles are designed and shaped so that there are no areas in which the true elongation is less than 4 per cent. Bearing in mind that once established, stretcher-strain markings persist most stubbornly, multi-stage operations should be arranged, whenever possible, so that low elongation areas are avoided or cut down to an absolute minimum.

Blue-brittleness

Blue-brittleness is a defect which is particularly met with in the enamelling, japanning, and hot-galvanising industries. It shows in low-carbon steels which are heated to 150° to 300° C. after being cold worked, and is often seen in a very pronounced form. The greatest safeguard against it is to continue to rely on sources of supply which have given a sheet metal in which the defect does not appear. Blue-brittleness will often appear when a new supply of sheet is used and before it is realised that special precautions have to be taken which were not necessary with previous sheet.

The cause of the defect is uncertain, but it is definitely not com-

parable with season-cracking in brass. Although it does not advance us very far to say so, it is more than possible that what is called the space lattice of the metallic crystal structure is so severely strained by recrystallisation at 300° C. that brittleness is engendered.

What is extremely interesting is that steel which develops blue-brittleness shows violent fluctuations in the stress-strain curve when tested at 200° C. Above and below 200° C. the curve is quite regular. It is reasonable to suppose that these violent fluctuations are the result of something happening on the slip planes of the crystal aggregate. The rate of work-hardening is not enough, probably, to enable the spill planes to re-orientate and distribute stress to neighbouring crystals.

The defect has been carefully gone into from the point of view of the chemical composition of the steel used, but the results are far from illuminating. Carbon alone is not the cause, otherwise all low-carbon steels would show it. Medium-carbon steels are not liable to the trouble to anything like the extent of the low-carbon steels used in the press shop. Phosphorus, undoubtedly, has an effect, but it is only part of the story, for low phosphorus content, although a safeguard, is no guarantee that the difficulty will not show itself.

There is no doubt as to the importance of nitrogen as a cause of blue-brittleness, for it will invariably appear in any low-carbon steel in which nitrogen is present to a relatively high extent. Open-hearth steel contains little nitrogen, Bessemer steel a considerably higher amount. That is why Bessemer steel should not be used, and the added safeguard should be taken of ensuring that the content of phosphorus is as low as possible.

Blistering

"Laminated" is the term used in press work to describe sheet which contains more or less continuous planes of non-metallic inclusions. Under severe operations such metal will fail entirely, but even when more gently treated, so that it takes the shape aimed at without fracturing, it will, nevertheless, have a characteristic blistered appearance. The experienced examiner of sheet metal can foretell such behaviour, for the presence of a faintly blistered look on the surface of finish-rolled sheet will indicate the presence of slag, the cause of internal discontinuity of structure of which the blister effect is the outward sign. A simple practical test is to bend a test strip of the sheet into a small arc and restraighten. The surface will blister if internal discontinuity exists.

Users of sheet steel are apt to attribute all slag inclusions to "pipe." This is not correct. True, in "killed" steel the main pipe is the site of slag inclusion of this kind; but in rimmed steel, slag forms in detached pockets as the metal cools, so that to ascribe all slag inclusions to faulty cropping is wrong.

There may be slag inclusion which does not show itself on the sheared

edge of a sheet because it does not run as far as the edge, and even when it does the closing effect of the shears will prevent anything being discernible.

Earing

The most marked directional effect is the formation of ears during deep drawing. This not only increases scrap but, more important, there is greater liability to fracture with a sheet with marked directionality than with one with random properties. A very great deal is now known about ear formation, the conditions which are conducive to it and the various methods of avoiding it, but, even so, earing difficulties have been by no means banished from the press shop. They are still frequently met with and are not easy to overcome.

Ear formation is favoured by high reductions and by high annealing temperatures. Pure metals form ears more easily than when there are certain amounts of impurities present, or, to put it in another way, when there are minor constituents. The directionality of mechanical properties of sheets originates from the characteristics of the individual crystals which possess different properties in different directions. The properties of rolled and annealed sheet vary, for the most part, in different directions according to the preferred orientation structure. The properties of sheet appear to be mainly determined by the preferred orientation of the grains in the crystallographic fibre.

A special test has been put forward as a means of assessing the potentialities as regards earing of deep-drawing sheet. It consists in making several pairs of slits or cuts in different directions—parallel, at 45 degrees and perpendicular to the rolling direction of a suitable piece of sheet. Pieces of these small short slips, about $\frac{3}{8}$ in. apart, are then torn from the sheet metal. The length of the tongue or tear formed in this way may vary considerably in sheet with marked directionality.

Fouling : Loading : Galling

" Loading " of tools implies the actual welding of their surface to the metal being drawn. " Galling " is another term used to describe this most troublesome defect due to tools and work coalescing. It is costly, not merely because it holds up production, but because the damage to the tools will be irreparable unless the loaded areas are immediately polished out. The removal must be complete because if even traces are left the process takes place again, immediately operations are resumed. If there is any attempt to carry on production, scoring is inevitable.

Lubrication is obviously all-important in avoiding fouling and loading and the reader is referred to Chapter VIII for more detailed information on this important subject. The whole subject is generally regarded as touching that mysterious, indefinable but nevertheless real quality " the nature " of the metal—not only that of the metal being drawn but of that

of the tools. Pressure between tools and work, the hardness and smoothness of the tools, and the speed of drawing are all involved. But the function of lubrication is to prevent surfaces running one into the other, and in the light of what we know of surface phenomena it is as well to think of this trouble in terms of lubrication. It is no contradiction to admit that contact pressure between work and tools is the primary condition which determines whether fouling will or will not take place.

As long as there is a continuous film of lubricant between work and tools, fouling cannot take place. A solid filler will often overcome the trouble.

Polish on the tools is very important, and if a set which has been in disuse or treated badly starts to give trouble, it is often found that restoring the finish does away with it. The hardness of the tools is important, too. That is, hardness as distinct from smoothness. Foreign particles are, of course, always a menace since they break down the lubricating film. Speed of drawing must also be considered, for increases of temperature locally, of the order of 1,000° C., may occur and the only means of dissipating the heat and preventing the running together of surfaces may be a slower draw. Another very practical aspect of this matter of speed is that the lubricant must be given time to spread.

In their ascending order of liability to foul tools made of steel, the following may be taken as a reasonably practical guide : brass, steel, austenitic steel, nickel silver, copper, aluminium, aluminium-bronze, cupro-nickel. It must be clearly kept in mind that it is not merely a matter of softness. Aluminium is soft, but it ranks high in the list of difficult metals in the press workshop.

Work should not be pressed immediately after pickling, if pickling forms part of the work layout. The process destroys the surface layer which is protective against fouling. That is why it is often found that metals which have been working satisfactorily will suddenly, after pickling, give trouble. The same thing often happens when goods have been interstage bright annealed in a furnace with a controlled atmosphere. Here again the surface film has been destroyed. The difficulty can be overcome by careful control of temperatures.

Wrinkling and Puckering

These two defects are notoriously prone to occur with the first set of tools designed for a particular job. In the past there has been an unfortunate tendency for the production side to blame the tool designer and the tool designer to blame the metal. " Bad metal " has been too easy an excuse. Nothing can be said of the skill and sixth sense, as regards his job, of the experienced tool setter. But there is no excuse for the use of loose phrases like " bad metal."

Wrinkling is the production of corrugations in that part of a blank which has not passed over the radius of the die. Owing to the reduction

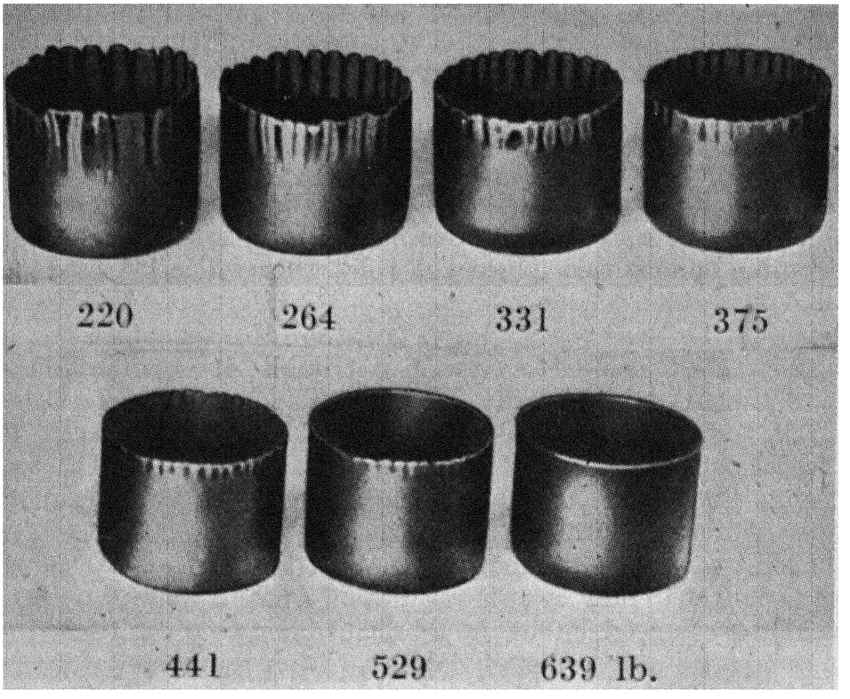


Fig. 1.—INFLUENCE OF PRESSURE-PLATE LOADING ON WRINKLE FORMATION (*Sachs*)

in perimeter which a blank suffers in the process of a draw, the outer surfaces must either thicken or wrinkle. In drawing non-circular shapes, the problems of wrinkling become more acute and, indeed, in rectangular articles it cannot be avoided, although it can be controlled and directed to that portion of the blank which is finally sheared off.

Under precisely similar working conditions—a given set of tools and blanks of the same size and thickness—two metals will behave differently. An extremely informative series of experiments by Sachs ("New Researches on the Drawing of Cylindrical Shells," *Proc. Inst. Auto. Eng.*, 1934–5, XXIX, p. 588) has shown how much variations in pressure-plate loading, other conditions remaining unchanged, influence wrinkle formation. By gradually increasing the load the defect was gradually eliminated. There must, of course, be an optimum figure. For whilst (bearing in mind that once formed, wrinkles will grow and push up the pressure plate) it is easy enough to apply a pressure which prevents wrinkles starting to form, that pressure may prevent the passage of sheet metal between pressure-plate holder and die, so that the wall of the deepening cup is stressed to the point of fracture. In practice the selection of an "oily" lubricant will enable sufficient loading to be applied so that wrinkling does not take place.

Puckering.—Wrinkling and puckering go hand in hand. Those metals which wrinkle also pucker easily, and aluminium is a good example of this. The defect is due to a number of different factors—lubricant, drawing-die radius, shape, thickness and size of the blank, and, above all, on the hardness and crystalline structure of the metal being drawn. Steel and brass will not pucker where aluminium and zinc will show the defect all too easily, under precisely the same conditions. The effect of crystal structure is not known with certainty, but an over-annealed batch will show the defect, indicating that large crystal size is an important contributory factor. The wrong lubricant, one that is not "oily" enough, will cause puckers to appear where before the particular draw was satisfactory. And the reverse is, of course, true. Comparatively slight changes in shape of the article will cause or eliminate puckers.

Speaking generally, reduction in the radius of the die will generally decrease the tendency to pucker but increase the tendency to wrinkle. Only careful tool design can achieve the satisfactory compromise.

Scoring

Where final appearance is important, scoring, or the formation on the surface of drawn work of grooves or score marks, during its passage through the die, is a very real trouble.

Surface irregularities on the tool surfaces, extraneous particles embedded in the surfaces of tools or work and, in general, dirt or matter in the wrong place, whether borne by lubricant, the operator's hands, or by the air, are all contributory causes. Two blanks going in instead of one will damage a set of tools so that scoring marks begin to show: the incomplete removal of previous scoring or loading is another cause. Very hard tools should, presumably, be less liable to score than those which are relatively soft. But this may be contradicted in practice, the exact reverse sometimes happening.

Whilst the fouling type of scoring can generally be dealt with by the correct choice of lubricant and avoiding areas of high pressure, the best remedy for genuine scoring is the maintenance of a high standard of shop cleanliness and a high regard for the care of tools.

Fire-cracking

Metals vary considerably as regards this defect, which is due to the too rapid heating of severely stressed articles. Nickel silver is notoriously prone to it. It may occur during annealing or in machining. The phenomenon is more likely to occur with alloys of low purity and coarse grain structure than in purer and finer-grained alloys. The possibility of fire-cracking occurring is obviated by a stress-relieving anneal at 250° C. to 300° C.

This same tendency to fracture or "fire-crack" is also seen in brass containing 65 per cent. of copper if either lead or iron is present. Lead

is more marked in its effect when present to the extent of from 0·25–1·2 per cent. Iron has nothing like the same effect as lead in sharply influencing the exhibition of "fire-cracking," and even then the iron content must be comparatively high (0·09 to 0·15 per cent.). It has also been noticed in bronzes, increasing with increase in tin content.

The majority of metals do not show the phenomenon, and when it does show itself the use of a continuous furnace in which the work is introduced gradually into the heated zone usually overcomes the difficulty.

Scaling

This is an annealing defect, at best objectionable, sometimes actually harmful, because tools are scored in subsequent operations. Pickling is expensive and a dirty operation. Modern furnaces for "bright annealing," with their controlled atmosphere, overcome the trouble, but in muffle furnaces proper much can be done by rigidly dealing with air leaks so that surface oxidation is eliminated. Packing the work in boxes with charcoal is another alternative.

Staining

Careless handling of pickling operations accounts for common staining troubles—to lack of cleanliness in the bath or during handling or slinging prior to immersion, to inadequate drying or subsequent protection of pickled surfaces, etc. Such troubles should not arise or, if they do, they can be dealt with readily.

An entirely new type of staining trouble arises with the modern controlled-atmosphere annealing furnace. So clean chemically is the work surface as it comes from the furnace that it reacts easily with the air or any fume that may be in the atmosphere unless some protective coating is applied at once.

The inadequate removal of drawing lubricants, which is dealt with in Chapter VIII, is the most common form of staining.

Surface Blemishes

Spots and specks, defects which are of economic importance in work in which a high degree of surface excellence is called for in the finished work, may be caused (1) by discontinuities, cavities, or inclusions just below the surface of the sheet metal used, (2) by foreign particles becoming embedded during drawing, (3) by particles of solid or drops of liquid which settle on the finished surface.

Defects due to the first cause can only be minimised by subjecting the original sheet to as rigid an inspection as possible, but even then they may be so small as to escape notice, and only show up during operations in the shop, when they entrap lubricant or pickling solution, which is either subsequently exuded or becomes a focus of corrosion. Metallic

particles can be picked up during the progress of the work through the press shop, during storage in bins or in the course of transport. Non-metallic particles are picked up during grinding. Special care should always be taken with aluminium work, for all sorts of outside matter can all too easily become embedded in its surface. Steel particles often become embedded in the surface of non-ferrous articles.

Nickel silver is extremely sensitive to surface marking, and finger marking is a defect which has been the cause of endless trouble to suppliers of sheet metal. On the finished sheet, after polish rolling, are found faint marks in the form of finger or hand prints. Microscopic examination shows the whorls and loops typical of skin markings on the hands. Investigation showed that these markings were most probably on the metal as far back as stage three in the process of production, and were due to handling after the first pickling.

Thus an oily hand mark may be left on the surface of the metal after the ingots have been inspected, and the latter are then stored for several days before being rolled, and during this time the hand or finger print is collecting dust and drying out. Then the ingot is rolled and the print rolled into the surface.

It has been remarked that the defect is more noticeable when the metal is bright annealed than when it is muffle annealed, and the explanation of this is obvious. In the muffle furnace the surface is oxidised and when scale forms and burns off, the defect is burned off at the same time. This phenomenon in nickel silver serves to bring out the point that where the appearance of a finished article is all-important, too much care cannot be taken to guard against spotting and specking arising owing to adventitious surface marking which seem altogether too slight to have any effect. In practice, when goods are sometimes held up, the harm done to the surface may render them unsaleable.

To clean and dry work thoroughly is the best safeguard against spots and specks due to drops of lubricant, pickling or cleaning solutions, or even water. It must be kept dry and covered afterwards, for minute particles of soot and dust are hygroscopic and attract moisture from the atmosphere and with it sulphur, a corrosive which is invariably present, even in minute quantities, in the air of a press shop.

Waving

Waving or rippling is a defect which takes the form of depressions, more or less severe, parallel to the direction of rolling of the sheet metal: when the depressions on the outer and inner surfaces coincide, as they often do in severe cases, they form an actual elongated neck in the metal.

Brass of low copper content usually shows the defect most severely, and the presence of streaks of beta brass in the sheet is given as the cause. Whether or not this is the whole of the story, when waving appears and

threatens to persist, a change to a sheet metal with a higher copper content is indicated.

Some press workers who have studied the subject and who are entitled to be heard with respect, take an entirely different view and ascribe the trouble to the inclusion of oxides of copper. They claim that waving can be produced at will from this cause, and point out that 63 per cent. copper-content brass is particularly prone to waving. It is, of course, a type of brass which is frequent in hot breaking down, and in the process the oxides of copper form and are absorbed or rolled into the body of the metal. The additional fact is adduced that cartridge brass, in which the defect is practically never seen, is broken down, for the most part, in the cold state.

Quench-roughness

Brass sheet which has been water quenched after annealing will, on being subsequently worked, develop a surface roughness reminiscent of orange peel. In fact, the appearance is much more like an " orange-peel surface " than the surface of metals to which it is usually applied, and is due to unusually large crystal size. Under the microscope there is no difference at all in the structure of brass which has been quenched, some of which will show quench-roughness and some of which will not.

The defect is particularly liable to appear when the copper content of the strip is in the region of either 63 or 75 atomic per cent., the latter being more susceptible. The harmfulness of roughness caused in this way depends on the purpose for which the drawn work is to be used. If a high finish is involved, it is often cheaper to reject a whole batch rather than try to smooth them off.

Quench-roughness in purchased strip is usually traceable to hosing with cold water of the strip as it comes away from the muffle. There can be no possible doubt that although the microscope shows no change in crystal structure, there is a profound change in atomic structure, and X-ray examination reveals that this is so.

Complications due to Defective Blanking

Too much is often taken for granted in blanking. Fractures under the press may be due to bad shearing. It is very often forgotten that sheet in the best condition for deep drawing is in its most plastic state, which is the condition most unsuitable for clean-cut blanking and shearing. The elastic condition of the metal is all-important, and two sheets whose physical constants are in every respect identical will behave quite differently when blanked. The one will show a clean-cut edge and give every satisfaction under the press, whilst the other will show a burred, overhanging edge and failures under pressure will be alarmingly high.

Severe burring may occur in blanks when tools are used with a clear-

ance which does not suit the metal. With really badly burred blanks, the action of the pressure plate during the first portion of a draw will be seriously prejudiced, and there is no proper control. What undoubtedly happens, although it is often unsuspected, is that when the clearance between punch and die is small, in a draw-through operation the sudden obstruction which the burr offers as it enters the confined space after leaving the die sets up a strain which causes the drawn shape to fracture. Clean-cut blanks obviate this danger.

Stress-cracking

With excessive cold working, materials which work-harden rapidly will develop high internal stresses that may become greater than the cohesive strength of the grain boundaries. This usually results in stress-cracking, which is recognised readily by the appearance of vertical cracks beginning at the rim in drawn shapes.

The container shown in Fig. 2 is a typical example of the results of excessive cold working; that shown at the right in the same figure was given exactly the same reduction as the fractured shell. The original blank of the good shell had a softer initial temper than that of the split shell. Neither was annealed, either between drawing operations or after the final draw.

Another interesting comparison is shown in Fig. 3. Both were drawn from blanks as those used to form the shell in Fig. 2 which fractured. Both were given the same reduction without intermediate annealing. A small rim was left on one and it remained perfectly sound. The flange served to reinforce the rim, where stress cracks normally begin. This is sound practice where the total reduction of the

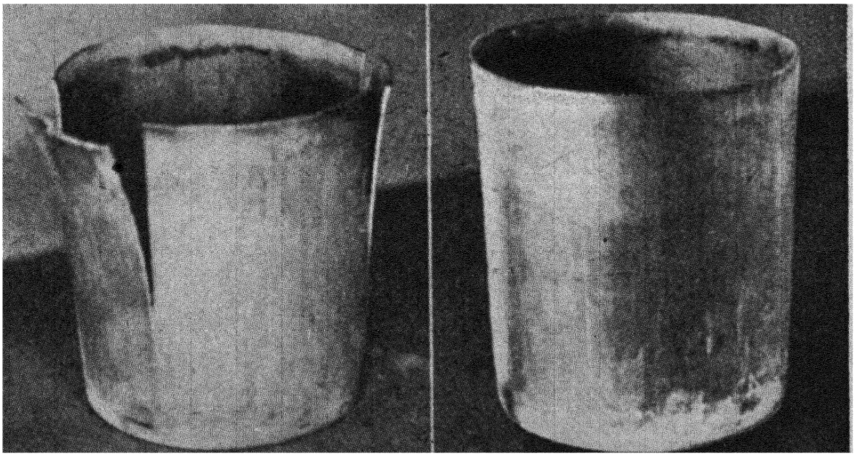


Fig. 2.—DEEP-DRAWN MONEL SHELLS, 5 IN. DIAMETER, $5\frac{1}{8}$ IN. DEEP, THREE DRAWS, NO ANNEALS. SPILT SHELL FROM HARD BLANK, GOOD SHELL FROM SOFT BLANK

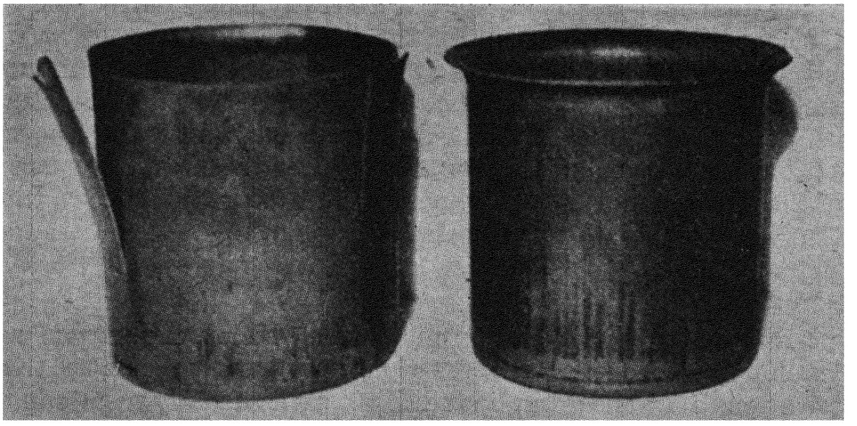


Fig. 3.—MONEL SHELLS SIMILAR TO THOSE ILLUSTRATED IN FIG. 2. BOTH WERE DRAWN FROM HARD BLANKS, THE SHELL WITH FLANGE REMAINING UNFRACTURED

drawn shell is likely to be high and there is possibility of fracture due to stress-cracking.

Cracks of the type shown on the left in Fig. 3 have been traced to rough edges on the initial blanks, due to dull tools. Wrinkles set up about the rim in the early draws and subsequently ironed out will set up uneven stresses round the rim which may induce stress cracks.

Stress-cracking of Monel and Inconel on deep drawing is minimised if a slight wall-reducing operation occasionally accompanies the diameter reductions. If heavy drafts are taken between anneals, it is very important to keep the containers free from deep vertical die scratches.

Failures due to Tools and Bad Setting

The influence of speed of drawing has been already mentioned. In a short account of the subject such as this, it is impossible to avoid being brief to the verge of sketchiness, but no apology need be offered for recalling certain points which should always be kept in mind.

Perfectly good metal will not give satisfactory work if tools are incorrectly designed and improperly set. Stainless steels require that the most severe draw should be the first draw, whilst the exact opposite is required with non-austenitic or ferritic steels. The fact is well known that a first deep draw on aluminium with a subsequent much milder one produces a deeper shell than if the processes were reversed.

Pressure-plate loadings should be watched to see that an intolerable strain is not placed on perfectly good sheet metal. If they are so high that there is practically no margin of safety in a draw, then perfectly normal variations in the sheet will cause failures. Wrinkling, on reduction of the pressure on the plate, will show what is happening. A wrong method of getting the desired shape is being used.

Troubles Arising from Annealing

Unsatisfactory inter-stage annealing is an important cause of press-shop difficulties. Modern furnaces are capable of being closely controlled and even those of older design can be fairly effectively handled if pyrometers (in the plural) are used and, like any other scientific tools, put to the use for which they are intended. With the mistaken idea of speeding-up production figures, time and temperatures are often cut down : satisfactory time and temperature handling is sometimes vitiated by too slow subsequent cooling : cracking due to too rapid heating, the formation of surface scale, and blistering are other types of failure to achieve a good result.

Under-annealing is not a serious cause of failure, though the modern method of using short-time heating in continuous furnaces demands that control should always be thoroughly efficient, if all danger is to be averted.

Difficulties which Arise in Polishing after Drawing and Pressing

Stepping-up of production rates is responsible for much of the trouble coming under this heading. Metal is often wrongly blamed : for work may be enamelled without adequate surface preparation. Plating is often done on brass after light polishing, without rough emery bobbing.

Draws which in modern practice become more and more severe open up the texture of sheet metal and add to the difficulty. Looking at the matter quite fairly, it cannot be denied that the metallurgists have given to the press worker metal with surface properties greatly in advance of anything known before. Austenitic steel and cold-rolled quality brass sheet are good examples. But good metal deserves good treatment and should be properly exploited and its valuable properties taken full advantage of in the right direction.

Mechanical as opposed to hand polishing brings its own problems, and where high contours in finished work, resulting from heavy draws, have to be dealt with, mechanical polishing is at a disadvantage.

The manufacturers of abrasives have a very clear knowledge of what is suited to various metals and conditions, but that full advantage is taken of that knowledge is doubtful.

Season-cracking of Brass

The spontaneous cracking of deep-drawn or pressed cold-worked brass, in spite of the advance in our knowledge of its cause and prevention is still a problem. Obviously it is a manifestation of internal strain. Any theory of the stress-cracking of brass must explain the most important recognised general features of stress-cracking. Among these generalisations are the following :

(1) Single crystals are not subject to stress-cracking, and the presence of crystal boundaries is a necessary condition.

(2) The tendency to crack and the rate of cracking decrease with decreasing grain size, that is with increasing area of grain boundary material.

(3) The phenomenon of season-cracking in brass is essentially intercrystalline in nature.

(4) Some chemical action must occur between the metal and another chemical substance.

(5) With increasing tensile strength the tendency to crack increases also, and, what is more, this increase is rapid. The tensile stress must be present at the surface exposed to chemical attack. Stress-cracking in brass is not a slow progressive process and the actual time taken from start to termination is usually very short in comparison with the time taken to initiate the cracking. Moreover, it seems that a certain minimum tensile stress is needed to start the fracture in brass. This is in direct contrast to what happens with certain aluminium alloys which are also subject to stress-cracking ; in them it occurs, it would seem, at very low or even, presumably, at zero stress. The chemical composition of the metal, the outline of the finished work, and the properties of the surrounding atmosphere, all have their effect in determining whether or not an article with internal stress is going to fracture. The higher the copper content of the alloy, the less the danger. Phosphorus and tin seem to have a certain inhibiting effect. The surrounding atmosphere can do extraordinary things to brass.

The simple mercurous-nitrate test gives a very clear indication of whether or not the internal strains in a cold-worked brass are of the order that will possibly result in fracture in the future.

Low-temperature annealing, following on rapidly in the work layout, is the effective treatment for eliminating season-cracking. It should be done after *all* cold working is done. Half an hour at not less than 250° C. is necessary. Where work piles up during successive stages of drawing, particular care should be taken of the conditions of storage and, if necessary, an additional low-stage anneal should be given if a prolonged period of rest, before completion, can be foreseen. When finished work has been sold and passed into use, and then sent back with complaints of fracture, it is not always easy to decide whether season-cracking or stresses in use are involved. If the cracks follow an erratic course, and their location is that of the most severely stressed parts, they are probably due to the first ; but if they have their origin at foci where service strains and stresses concentrate, the alternative explanation must be considered.

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BRINELL HARDNESS NUMBER TABLES

The chart showing Brinell numbers, arrived at from the use of the 5-mm. ball, is considered useful in determining the hardness of sheet metal which would be too thin to test with a 10-mm. ball. The other chart, in which a 10-mm. ball is used, is not new except that it shows the Brinell number with a 1,000-kg. load. This 1,000-kg. load is applicable for testing bronzes and aluminium alloys for which the 3,000-kg. load is too much and the 500-kg. load too little.

A recommended standard practice for the preparation of surfaces for Brinelling is as follows :

For a 10-mm. ball and a hardness number less than 248, fine grinding or filing is satisfactory. For hardness numbers higher than 248, fine grinding with an emery-cloth polish is recommended. For the 5-mm. ball use emery-cloth finish.

For permission to use Tables I and II we are indebted to Messrs. E. W. Bliss and Co. Ltd., whose metallurgist, Mr. T. N. Holden, Jr., was responsible for their compilation.

TABLE I.—BRINELL HARDNESS NUMBERS

Diameter of Ball, 5 mm.

Diam. mm.	*Load Kgms.*		*Diam. mm.*	*Load Kgms.*		*Diam. mm.*	*Load Kgms.*		*Diam. mm.*	*Load Kgms.*	
	750	250		750	250		750	250		750	250
1·00	945	315	1·50	415	138	2·0	229	76·3	2·50	143	47·5
1·025	899	300	1·525	401	134	2·025	223	74·3	2·525	140	46·5
1·05	856	285	1·55	388	129	2·05	217	72·4	2·55	137	45·5
1·075	817	273	1·575	375	125	2·075	212	70·6	2·575	134	44·6
1·10	780	260	1·60	363	121	2·10	207	68·8	2·60	131	43·7
1·125	745	249	1·625	352	118	2·125	201	67·2	2·625	129	42·7
1·15	712	237	1·65	341	114	2·15	197	65·5	2·65	126	41·9
1·175	682	227	1·675	331	111	2·175	192	63·9	2·675	124	41·0
1·20	653	218	1·70	321	107	2·20	187	62·4	2·70	121	40·2
1·225	626	209	1·725	311	104	2·226	183	60·9	2·725	119	39·4
1·25	601	200	1·75	302	101	2·25	179	59·5	2·75	116	38·6
1·275	578	193	1·775	294	98	2·275	174	58·1	2·775	114	37·8
1·30	555	185	1·80	285	95·0	2·30	170	56·8	2·80	111	37·1
1·325	534	178	1·825	277	92·4	2·325	167	55·5	2·825	109	36·4
1·35	514	171	1·85	269	89·7	2·35	163	54·3	2·85	107	35·7
1·375	496	165	1·875	262	87·3	2·375	159	53·0	2·875	105	35·0
1·40	477	159	1·90	255	84·9	2·40	156	51·9	2·90	103	34·3
1·425	461	154	1·925	248	82·7	2·425	153	50·7	2·925	101	33·7
1·45	444	148	1·95	241	80·4	2·45	149	49·6	2·95	99·2	33·1
1·475	429	143	1·975	235	78·4	2·475	146	48·5	2·975	97·3	32·4
									3·0	95·5	31·8

TABLE II.—BRINELL HARDNESS NUMBERS

Diameter of Ball, 10 mm.

Diam. mm.	Load Kgms. 3,000	1,000	500	Diam. mm.	Load Kgms. 3,000	1,000	500	Diam. mm.	Load Kgms. 3,000	1,000	500	Diam. mm.	Load Kgms. 3,000	1,000	500
2·0	945	315	158	3·00	415	138	69·1	4·0	229	76·3	38·1	5·00	143	47·5	23·8
2·05	899	300	150	3·05	401	134	66·8	4·05	223	74·3	37·1	5·05	140	46·5	23·3
2·10	856	285	143	3·10	388	129	64·6	4·10	217	72·4	36·2	5·10	137	45·5	22·8
2·15	817	272	136	3·15	375	125	62·5	4·15	212	70·6	35·3	5·15	134	44·6	22·3
2·20	780	260	130	3·20	363	121	60·5	4·20	207	68·8	34·4	5·20	131	43·7	21·8
2·25	745	248	124	3·25	352	117	58·6	4·25	201	67·1	33·6	5·25	128	42·8	21·4
2·30	712	237	119	3·30	341	114	56·8	4·30	197	65·5	32·8	5·30	126	41·9	20·9
2·35	682	227	114	3·35	331	110	55·1	4·35	192	63·9	32·0	5·35	123	41·0	20·5
2·40	653	218	109	3·40	321	107	53·4	4·40	187	62·4	31·2	5·40	121	40·2	20·1
2·45	627	209	104	3·45	311	104	51·8	4·45	183	60·9	30·5	5·45	118	39·4	19·7
2·50	601	200	100	3·50	302	101	50·3	4·50	179	59·5	29·8	5·50	116	38·6	19·3
2·55	578	193	96·3	3·55	293	97·7	48·9	4·55	174	58·1	29·1	5·55	114	37·9	18·9
2·60	555	185	92·6	3·60	285	95·0	47·5	4·60	170	56·8	28·4	5·60	111	37·1	18·6
2·65	534	178	89·0	3·65	277	92·3	46·1	4·65	167	55·5	27·8	5·65	109	36·4	18·2
2·70	514	171	85·7	3·70	269	89·7	44·9	4·70	163	54·3	27·1	5·70	107	35·7	17·8
2·75	495	165	82·6	3·75	262	87·2	43·6	4·75	159	53·0	26·5	5·75	105	35·0	17·5
2·80	477	159	79·6	3·80	255	84·9	42·4	4·80	156	51·9	25·9	5·80	103	34·3	17·2
2·85	461	154	76·8	3·85	243	82·6	41·3	4·85	152	50·7	25·4	5·85	101	33·7	16·8
2·90	444	148	74·1	3·90	241	80·4	40·2	4·90	149	49·6	24·8	5·90	99·2	33·1	16·5
2·95	429	143	71·5	3·95	235	78·3	39·1	4·95	146	48·6	24·3	5·95	97·3	32·4	16·2
												6·00	95·5	31·8	15·9

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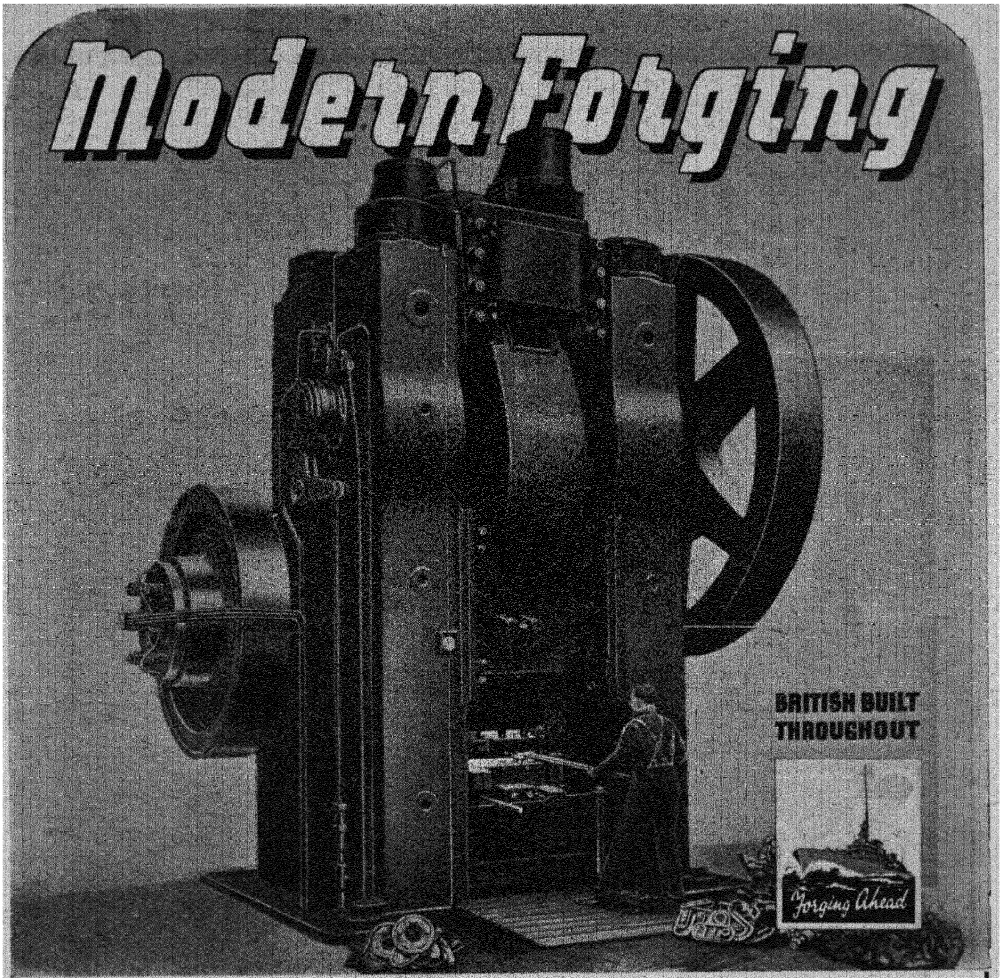
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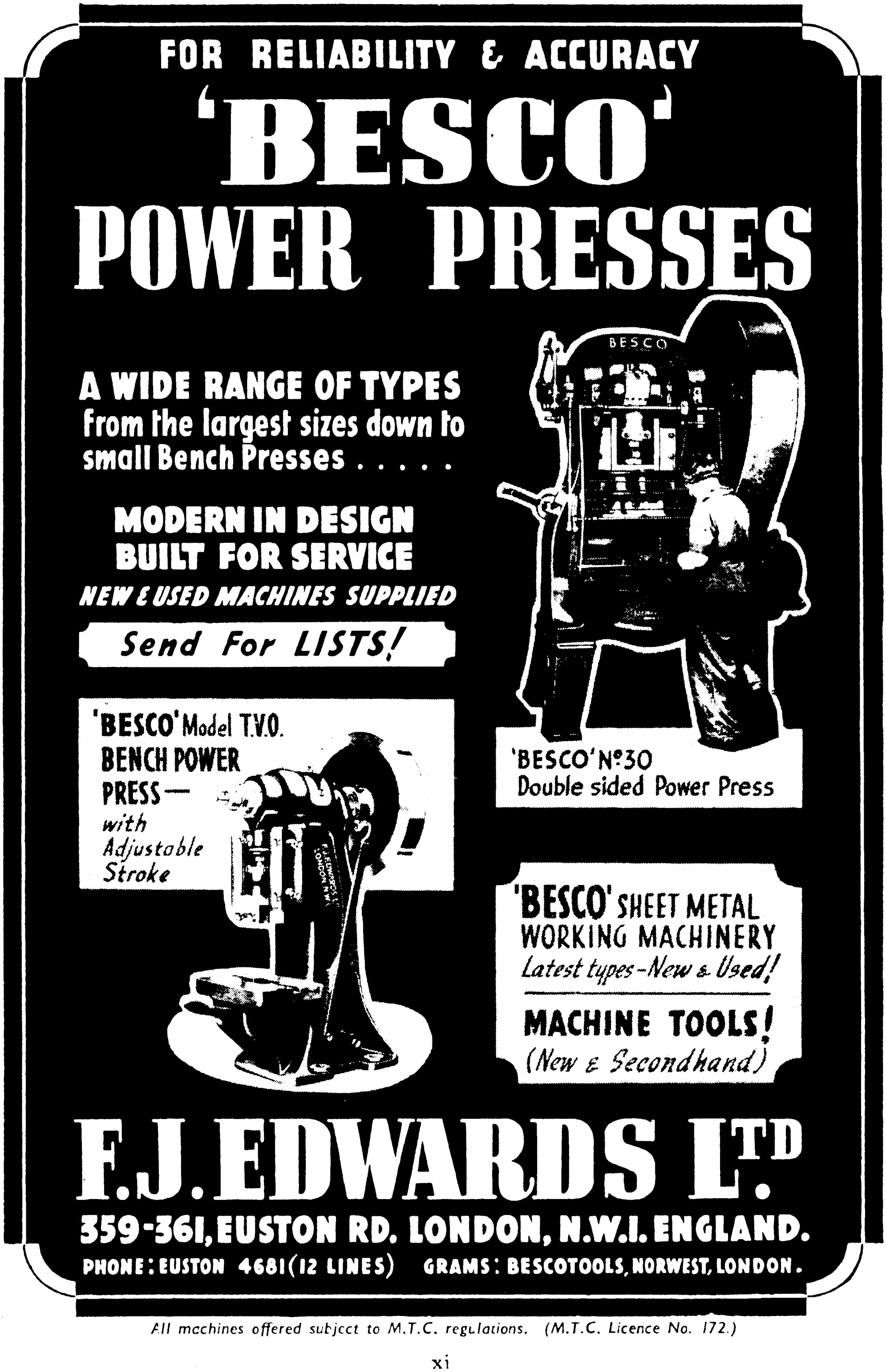

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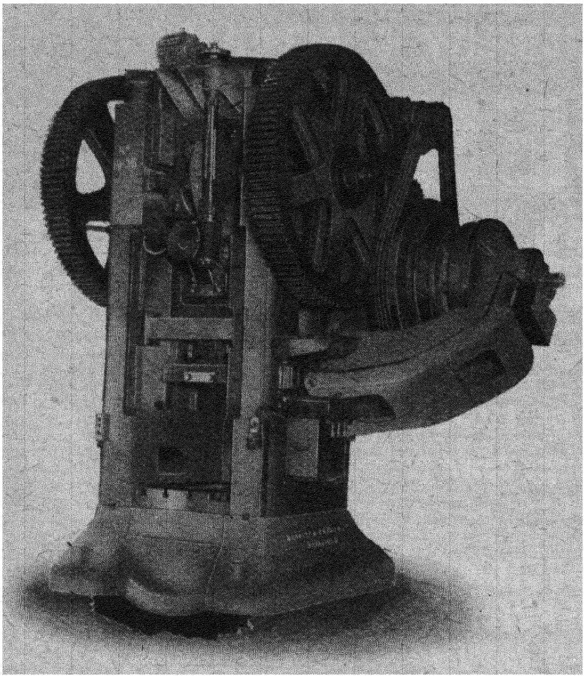

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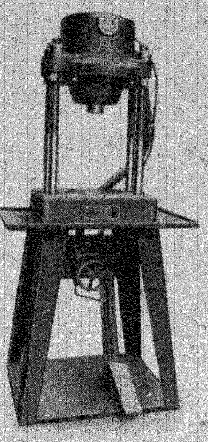

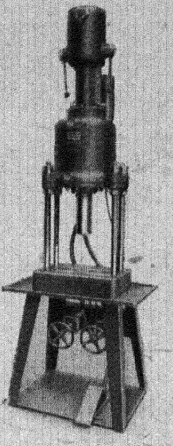

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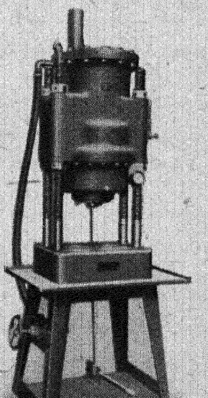

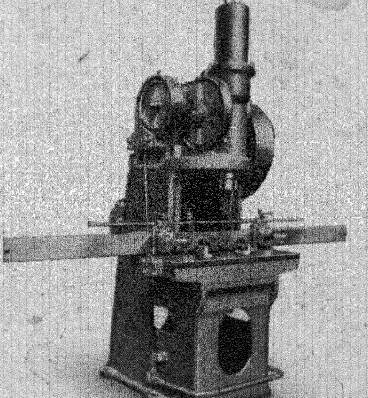

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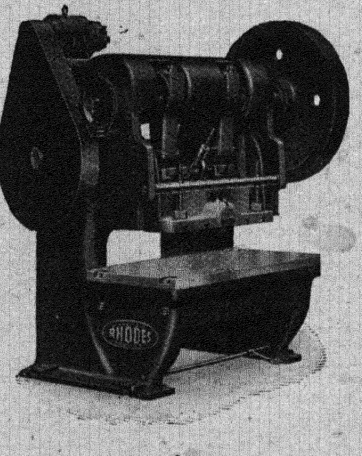

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